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THE HABITAT OF THE EURYPTERIDA

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THE HABITAT OF THE EURYPTERIDA

BY

MARJORIE O'CONNELL, PH.D.

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The Eurypterid Faunas and their Associated Organisms—*continued*

BULLETIN
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VOLUME XI JUNE, 1916 No. 3

THE HABITAT OF THE EURYPTERIDA[1]

BY

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INTRODUCTION

It has been the custom to consider that all fossils are the remains of marine organisms unless obvious and indisputable evidence of their fluviatile, lacustrine, or terrestrial habitat is available; a fossil found without any other associates has been held to be marine until proved to be otherwise, but never has the suggestion been made that such a fossil was fluviatile until proved to be marine. Yet such a suggestion would be most logical, and, as we shall see, it would be far more natural than the one usually made. The early fish have always been considered normally marine, though recent studies of the character of the sediments in which their remains occur has led many of the former advocates of the marine habitat to concede that the earliest fishes lived in non-marine waters, perhaps lacustrine, but most probably fluviatile. Similarly, limestone faunas were at one time referred without question to a marine origin, but we now know that limestones of purely marine organisms may be formed by eolian deposition, as in the case of the Miliolitic limestone of the Kathiawar Peninsula of Western India (Grabau, **87**, 574).[2] There is thus no *a priori* reason

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[1] This paper was awarded the Walker First Prize by the Boston Society of Natural History in May, 1914.

[2] Throughout this paper numbers in parentheses will refer to the bibliography at the end, p. 257; the full-face type referring to the titles with the same number, the light-face numbers giving page reference in the particular article.

for implicitly accepting the marine origin of all those rocks for which it has been claimed, nor for believing that all fossils found in the Palaeozoic rocks, with the exception of freshwater molluscs, plants, and insects, are the remains of marine plants or animals. Just as there is a growing tendency at the present time to recognize the importance of the wind and of rivers as agents of transportation and deposition in the past, so there is noticeable an awakening from the old belief that all fluviatile organisms began their life in the sea, and only after countless ages of evolution in that realm, migrated first into brackish water and then into the rivers.

The present paper deals with the habitat of a class of crustaceous animals widespread in the Palaeozoic and confined to it. The Eurypterida belong to the subclass of the Merostomata in the class Acerata of the phylum Arthropoda. Their nearest relatives are the limulids and scorpions with which latter group they have been classed by certain authors.

While it is generally accepted that some eurypterids lived in fresh water, the majority of palaeontologists at the present time still maintain that the early periods of the racial history of these organisms were passed in marine waters and that it was only, indeed, after their acme in development had been reached that these merostomes, becoming at first euryhaline, finally forsook the sea altogether and lived in rivers and in brackish water bodies until they became extinct at the end of the Palaeozoic. The evidence set forth in support of this hypothesis is so plausible that many have been led to think that there is a large and convincing array of facts sufficient to furnish an indisputable proof that the eurypterids lived during at least a part of Palaeozoic time in marine waters. It was with the purpose of showing that such a proof was really non-existent, and that the observed facts can also, and perhaps more rationally be accounted for in another way, that the present paper was undertaken. The author proposes to formulate a few of the principles which must be borne in mind in considering such a problem, and to point out the inconsistency in the lines of argument generally given to prove that the eurypterids were originally marine organisms. After a review of all the evidence available, the attempt will be made to judge it impartially and to determine which interpretation is really called for by the facts. The first chapter contains a record of facts, without comment; they are the data from which deductions are later made and of which interpretations are offered. These facts include: A, the distribution of all known species of eurypterids throughout the world; B, the horizons in which the remains occur, with particular reference to the facies exhibited and to the exact stratigraphical position; C, the mode of occurrence of the remains, whether well preserved or fragmentary, whether a single fragment or a large number of individuals; and finally, D, the other fossils, if there are any, which occur associated with the eurypterids. These facts are all summarized in tables I-III on pp. 37-49 and in the list of faunal associates on pp. 84-91. The second chapter is a résumé of the various opinions which have been held regarding the habitat of the Eurypterida. The next three chapters (III, IV and V) deal with the three chief lines of evidence which may be adduced to determine any fossil habitat, namely, the bionomic characters of the faunas, the lithogenesis of the formations in which the remains occur, and the type of migration and dispersal, marine or fluviatile, indicated by the relations existing between species and genera in synchronous faunas and by the phyletic relationships in successive horizons. In these three chapters general principles are first discussed and criteria are established for recognizing various types of habitats, sediments, and fossil faunas; the application of these criteria to the eurypterid problem is then given in detail. The conclusion reached by the author after the study of all available data and in the light of manifold theoretic considerations is that: *the eurypterids throughout their entire phylogenetic history lived in the rivers.*

Aside from the work done on the literature, a large amount of material has been studied, including hundreds of typical specimens of eurypterids, thin sections of some of the waterlimes, the collections of the rock types from the eurypterid-bearing horizons of Europe collected by Professor A. W. Grabau and now in the Palaeontological Museum of Columbia University; further, a number of the best sections in the field have been visited. When the present paper was nearly finished there appeared Clarke and Ruedemann's exhaustive Monograph on the Eurypterida of New York (**39**), which, with Woodward's Monograph of the British Fossil Crustacea, gives us the most illuminating and comprehensive work on the Eurypterida. Many important points in the ontogeny and phylogeny of the eurypterids are here set forth for the first time, and all of the North American species are described in great detail and figured in a volume of plates that surpass all former illustrations.

I wish to express my thanks to Dr. R. Ruedemann, who allowed me to study the large collection of New York eurypterids at the State Museum in Albany; to Dr. C. D. Walcott, who showed me the large Beltina fauna and the beautiful specimens of Limulava from the Middle Cambric Stephen shale of Canada in the Smithsonian Institution at Washington, D. C.; and to Mr. McIntosh at the Museum of the Natural History Society, St. John, New Brunswick, for information about the age of the Little River Plant beds and for the privilege of being allowed to inspect the type material from those beds.

To the courtesy and helpfulness of Mr. Henry R. Howland, Superintendent of the Buffalo Society of Natural Sciences, I owe the opportunity of studying every specimen of eurypterid in the museum of that Society. Furthermore, Mr. Howland loaned me a number of specimens to describe, and I was thus able to show the existence of two species of a pulmonate gastropod, Hercynella, in the Bertie waterlime. It was because of Mr. Howland's interest in papers dealing with the geological problems of the Buffalo region that the present contribution appears in the *Bulletin of the Buffalo Society of Natural Sciences*.

With the fullest appreciation for the inspiration and guidance which I have received, I gladly acknowledge my indebtedness to Professor Amadeus W. Grabau. He was one of the first to advocate the fluviatile habitat of the eurypterids and one of my earliest geological recollections was of a discussion between him and a number of men who argued for the marine habitat, a discussion to which I listened with the utmost interest although I was then not in a position to weigh the evidence brought forward on either side. More than four years ago Professor Grabau suggested that I take up the problem, with the purpose of marshalling all of the available evidence in proof of an hypothesis which he had strong theoretic reasons for believing to be true. Throughout the work I have profitted by the helpful criticisms and keen suggestions of a man who has made such problems his specialty for twenty-five years, and without whose assistance this paper certainly could not have been written. The method of treatment which I have used is based upon the principles of interpretational geology expounded in the Palaeontological Laboratory of Columbia University, and with the hope that this paper shall not prove unworthy of the teachings there set forth, I informally dedicate it to the American School of Philosophic Geologists, among the leaders of whom Professor Grabau stands so preëminent.

CHAPTER I

SYSTEMATIC REVIEW OF THE OCCURRENCE OF THE EURYPTERIDA IN EACH PERIOD FROM THE PRE-CAMBRIC THROUGH THE PERMIC

INTRODUCTORY

From all over the world there have been recorded fourteen genera and between 150 and 160 species of eurypterids. Of these considerably more than half occur in the Siluric, about a third occurring in the Upper Siluric alone. No remains have been found in beds higher than the Permic, and until 1882 it was supposed that there were none below the Siluric. In that year Walcott discovered a few fragments in the Utica shale, of Upper Ordovicic age, and an even more remarkable fauna in the Pre-Cambric Belt Terrane of Montana. In 1901 Beecher discovered an almost perfect eurypterid in the Upper Cambric of Missouri. These discoveries, together with several more recent ones from the Ordovicic, show that the Eurypterida ranged from the Pre-Cambric through the Permic, reaching their acme in numbers, development and diversity of types in the Upper Siluric. In the following review of the occurrence North America alone will be considered first and then the rest of the world. Until the *Monograph on the Eurypterida of New York* appeared there was no one book containing all the information about the North American species, and it was necessary for one in quest of such knowledge to search laboriously through state reports and numerous periodicals. Now all the data have been systematically brought together and greatly added to, so that it will be unnecessary to dwell at great length upon the American formations. For the rest of the world, unfortunately, there is no one book to which the student may be referred, so that one is compelled to consult the literature of each country in each continent thus gradually bringing together the work that has been done. Because the foreign periodicals and books now out of print are inaccessible to many, a more detailed account will be given of the distribution, and the nature and correlation of the formations in other countries than is required for America.

NORTH AMERICA

PRE-CAMBRIC. The earliest representative of the eurypterids is *Beltina danai* discovered by Walcott in the Greyson shales in the middle part of the Belt Terrane in Montana. The remains are very numerous, most of them being exceedingly thin films flattened in a calcareous shale and showing no definite surface markings (**288**, 21). Weller has collected specimens from the Altyn limestone at the type locality north of Altyn in the valley of Swift Current Creek, Montana, at the base of the Appekunny Mountains where the remains are embedded in a fine calcarenyte matrix and show surface markings (**288**, 40, pl. 7, fig. 4). Specimens have also been collected from the Altyn limestone at about the same horizon near Johnson Creek on The Continental Divide, Alberta, Canada. These show surface markings, and have been referred by Walcott to *B. danai* (**288**, 40, pl. 7, figs. 2, 2a, 3).

In a recent communication from Dr. Walcott, I have his statement about the occurrence of the merostome remains in the different sections. In the southeastern area of the Big Belt Mountains he found a series of sandy shales and sandstones between the top of the Newland limestone and the base of the Greyson; these carried Beltina. In the sections in the Little Belt Mountains Walcott found it difficult to determine whether the shales carrying Beltina belonged to the Greyson or to the Newland. In the Northern Montana section the merostome remains are found in the lower portion of the Altyn limestone, so that, concludes Walcott, "the correlation on the basis of fossil evidence is that the Greyson and Altyn are about the same age."[1] The fossils from the Altyn limestone were identified by Walcott as *Beltina danai*, and Clarke and Ruedemann agree that the fragments are remains of merostomes. They are, however, skeptical about the correlation of the Altyn with the Belt terrane and they are justified in this skepticism so long as the correlation is based upon the fossils alone, for if the organic remains in the Belt terrane are not eurypterids and are not the same as those in the Altyn, then the correlation is unfounded. Furthermore, the palaeontological evidence alone would not be sufficient for correlation, and, if, as I believe, these Pre-Cambric formations are to be regarded as of continental origin, then neither physical nor faunal data will lead to correlations, since the same lithological successions will be repeated time and again in different localities and in addition the synchroneity of river faunas is difficult to establish.

Thus at present it is impossible to say which authority is to be accepted. Walcott plans to do more work on these sections in the

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[1] Dated February 26, 1915.

course of which he may find better preserved fragments in the Belt terrane, leaving no doubt as to the nature of the organisms; or, he may find other structural and stratigraphic evidence for the correlation. "On the basis of lithologic characteristics," he says, "the Altyn would be correlated with the Newland limestone, and the Grinnell and Appekunny with the arenaceous series above the Newland limestone." But he further points out that "In deposits of the character of those of the Algonkian in Montana, lithologic characteristics are really of very little value over extended areas, as most of the calcareous formations are in the form of great lentils, and these are not comparable with the calcareous deposits of the Palaeozoic."

CAMBRIC. In the Middle Cambric there are undoubted marine Merostomata, discovered by Walcott in 1910 in the Stephen formation in British Columbia, Canada. He has described two genera, Sidneyia and Amiella, referring them to the Eurypterida in the suborder Limulava. As will be shown later, these forms are not true eurypterids, and need, therefore, no further mention here.

The only unquestionable eurypterid from the Cambric is Beecher's *Strabops thacheri* from the Potosi limestone at Flat River, St. François county, Missouri (**19**, pl. VII). Of this species a single specimen was found for which the genus was erected. It is a nearly complete individual, the dorsal aspect of which is well shown, though none of the appendages are visible. It occurs in a yellowish, argillaceous calcilutyte from one of the lower members of the Potosi. The slab upon which Strabops occurs contains no other organic remains,[2] but Beecher has described a collection made by Nason from these same beds in which there is an abundant marine fauna consisting of fragments of trilobites with a few brachipods and other forms (Hyolithes and a small Platyceras) (**20**, 362, 363). It is to be regretted that Beecher did not, or was not able to specify more exactly the stratum in which he found the eurypterid, for the Potosi limestone in the Flat River section is 350 feet thick, not counting the 106 feet of slates and conglomerate below and another 100 above, all of Potosi age, and of course, it is by no means certain that the marine fossils occurred in the same bed with the eurypterid. In fact, so far as the material is concerned, this seems not to have been the case.

ORDOVICIC. From the Ordovicic until just recently only one occurrence had been noted, that of *Echinognathus clevelandi* Walcott,

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[2] The type of this species is in Yale University, but the counterpart of the type is in Columbia University Paleontological Collection, specimen 18122.

described from the Utica shale of Holland Patent, New York (**281**), where one cephalic appendage and a portion of a thoracic somite were found. On the same piece of slate with these fragments Walcott found two characteristic Utica fossils, *Leptobolus insignis* and *Triarthrus becki*, and from the same locality comes a large graptolite fauna including *Dendrograptus tenuiramosus*, *Climacograptus bicornis*, as well as *Schizocrania filosa* and *Endoceras proteiforme*.

Lately there have been some extremely interesting discoveries of eurypterids in the Normanskill and Schenectady shales and sandstones (Black River and early Trenton age, respectively) of the Mohawk and Hudson valleys. Professor G. H. Chadwick has very recently found eurypterid remains in the sandstones of the Broom Street Quarry at Catskill, New York, in the Normanskill beds which until then had yielded only a graptolite fauna. Clarke and Ruedemann have described the species and also the beds from which they come. The eurypterids are very abundant in the sandstones though poorly preserved, but in the intercalated black shales, while less numerous they show better preservation. They are associated with graptolites and plant remains. Six species have been described by Clarke and Ruedemann. *Eurypterus chadwicki*, *Eusarcus linguatus*, *Dolichopterus breviceps*, *Stylonurus modestus*, *Pterygotus ?* (*Eusarcus*) *nasutus*, *P. normanskillensis*. Entire individuals are absent, the fauna being made up chiefly of carapaces.

The first profuse Upper Ordovicic fauna is found in the Schenectady shales (Trenton age), originally referred to the Frankfort. A preliminary notice of these specimens which appeared in 1910 (**38**, 31) shows that these remains "usually in fragmentary condition, abound most freely in fine-grained black shale, intercalated between thick calcareous sandstone beds. . . . . but they also occur in the sandy passage beds between the two. The sandy shales are full of organic remains, partly of the supposed seaweed *Sphenothallus* (*Sphenophycus*) *latifolium* Hall and partly of what appear to be large unidentified patches of eurypterid integument. In the black shales the eurypterid remains are rarer, but their surface sculpture is excellently retained, and here their organic associates are *Climacograptus typicalis* and *Triarthrus becki*. As a result of imperfect retention of these eurypterids in the rocks where they most abound and their sparseness in the shales which have best preserved them, we are still left in ignorance of the full composition of the assemblage, but it is safe to say genera, species and individuals were abundant at this early period and the evolution of distinctive characters . . . . had progressed to so sharp a differentiation that we are compelled to carry back farther in history, some of the commoner generic designations. These remains in the Frankfort [Schenectady] shale are distributed through fully 1500 feet of strata off a northeast-southwest coast line in an area of maximum deposition." Clarke and Ruedemann have described eleven species[3] *Eurypterus megalops*, *E. pristinus*, *E. ? (Dolichopterus ?) stellatus*, *Eusarcus triangulatus*, *E ? longiceps*, *Dolichopterus frankfortensis*, *D. latifrons*, *Hughmilleria magna*, *Pterygotus nasutus*, *P. prolifica*, *Stylonurus ? limbatus.*

A few fragments found as early as 1874 in the upper part of the Cincinnati group near Clarkesville, Clinton County, Ohio, were originally described by S. A. Miller (174) as *Megalograptus welchi*, under the mistaken supposition that they represented a graptolite, but were later determined by A. F. Foerste to be eurypterid remains. The specimens are much broken, representing two endognathites with one postabdominal segment. They occur in a blue marl three feet above a wave-marked layer of limestone, in the Liberty beds where they are associated with a typical marine fauna mainly of crinoids and some trilobites.

SILURIC. *Lower Siluric or Niagaran.* In the Lower Siluric are several cases of the presence of eurypterid remains in marine formations. Hall's species of *Eurypterus prominens* from the Clinton greenish sandstone of Cayuga County, New York, was described from a single cephalon, and an unidentified species of Eurypterus is recorded from the Arisaig of Nova Scotia (39, 87). Whiteave's *Eurypterus (Tylopterus) boylei* from the Guelph dolomites of Ontario is a species founded upon a single somewhat crushed, but otherwise nearly complete individual. It is found in a porous, coarse-grained dolomite, and shows an unusually thickened exoskeleton, a thickening common in other members of the Guelph fauna and indicating, according to Clarke and Ruedemann, extremely saline conditions (39, 218).

Quite recently a new eurypterid horizon has been discovered by M. Y. Williams in the shales overlying the Lockport and underlying the Guelph of Ontario, Canada. Along the banks of the Eramosa River between Rockwood and Guelph the top of the Lockport formation is exposed, and is seen to consist of a series of "thin-bedded, dark

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[3] *Eurypterus ruedemanni.* This name is proposed for the species called by Clarke and Ruedemann *E. megalops*, that name having been previously occupied by Salter (1859). The fact that Woodward referred Salter's species to Stylonurus does not restore the validity of the name *megalops* for Eurypterus.

grey or chocolate brown, bituminous dolomites which at some localities include bituminous shales," and to which Williams has given the name Eramosa beds (**303**, 1).

The bituminous nature of the dolomites and intercalated shales is indicative of near-shore conditions, and since these succeed the more purely marine facies of the typical Lockport, a shoaling or withdrawal of the sea, with a greater dominance of terrestrial sedimentation, is implied. The fauna is confined within some six inches of the bituminous shales and though fragments of a dozen or more species, including one eurypterid, have been found in abundance, not even generic identifications could be made with certainty. Williams gives the following list (**303**, 3):

Eusarcus logani Williams
Monomorella cf. orbicularis Billings
Orthis ? near tenuidens Hall
Spirifer radiatus Sowerby ?
Anoplotheca ? sp.
Lichenalia concentrica Hall
Orbiculoidea subplana (Hall)
Camarotoechia whitei (Hall)?
Whitfieldella nitida Hall?
Meristina ? sp.
Conularia niagarensis Hall?
Conularia sp.

The *Lower Siluric* occurrences, thus, are in formations containing undoubted and abundant marine faunas, but the eurypterids are represented either by fragments, or, in the case of the Guelph specimen, by a single though nearly perfect individual.

A recent discovery of considerable interest is the finding by Professor Van Ingen of Princeton University, of eurypterid remains in what appears to be the Tuscarora and associated beds of Swatara Gap, Lebanon County, Pennsylvania (**39**, 418, 419). In beds carrying *Arthrophycus harlani ?* he found:

1. *Eurypterus maria,* Large and small carapaces.
2. *Dolichopterus* cf. *otisius.* Medium sized carapace.
3. *Stylonurus myops.* Large and small carapaces .
4. *Hughmilleria shawangunk.* Large carapace.
5. *Pterygotus cf. globiceps.* Small carapace.
6. Swimming leg of a Pterygotus or Hughmilleria.

Another bed labeled 182 B 23 has afforded a carapace not distinguishable from *Eurypterus maria*. A bed, said to occur between a horizon containing what is apparently a Clinton fauna (B 8x) and one containing a Rochester (or Lockport) fauna (B 19x)and numbered B 16 h, contained the following remains:

1. Small carapaces, belonging to species closely related to or identical with *Eurypterus maria*, *Hughmilleria shawangunk* and *Pterygotus globiceps*.
2. A patch of integument with finely preserved sculpture identical with that ascribed to Stylonurus sp.
3. *Stylonurus myops*. Fragmentary, medium sized carapace.
4. Coxa, probably belonging to Hughmilleria.
5. Small telson of an Erettopterus.

Middle Siluric or Salinan. In the Middle Siluric of North America are several interesting occurrences of eurypterids, and the first appearance of well preserved individuals in large numbers. Specifically indeterminable fragments of Hughmilleria and carapaces of Dolichopterus (cf. *D. otisius*) or Hughmilleria have been found along the Pennsylvania-Maryland border in a hard black shale which is "sandy at the top and pitted by rust-stained worm-tubes" (**267**, 5), and which is interbedded between two sandstone members of the Keefer sandstone member of the McKenzie formation at the base of the Salina.

Of far greater interest and importance, however, are the faunas of the Pittsford and Shawangunk shales of New York and Pennsylvania. At Pittsford, Monroe County, New York, five species (or varieties) of eurypterids have been found: *Eurypterus pittsfordensis* Sarle, *Hughmilleria socialis* Sarle, *H. socialis* var. *robusta* Sarle, *Pterygotus monroensis* Sarle and *Stylonurus* (*Ctenopterus*) *multispinosus* Clarke and Ruedemann. This fauna is represented by numerous individuals, many of them well preserved, and by many fragments, but typical marine fossils are absent from the shales, although crustacea such as *Emmelezoe decora* and *Pseudoniscus roosevelti* occur. The eurypterids are here preserved in a remarkable state of perfection, the fauna being found in two thin layers of the black shales (lower one 1 foot 2 inches thick, upper one 10 inches thick) (**240**, 1082) and the eurypterids are in such abundance that some layers are "literally packed" with the remains. The entire fauna from these beds as reported by Sarle (**240**, 1081) is: Phyllocarida, 2; Synxiphosura, 1; Eurypterida, 6.

In the associated dolomitic layers were found Graptolitida, 1; Annelida (denticles), 3; Brachiopoda, 1; Pelecypoda, 1; Cephalopoda, 2; Ostracoda, 1.

A recent discovery by Professor Gilbert van Ingen has brought to light some eurypterid remains from a loose block found lying in Oriskany Creek, 3 miles south of Clinton, New York. Three carapaces and several other fragments were found, the block also being "full of lingulas and orbiculoideas" (**39**, 421). A new species, *Eusarcus vaningeni* Clarke and Ruedemann was made, to include these specimens which closely resemble *E. cicerops* of the Shawangunk of Otisville and may represent the adult of that species.

From the shale beds in the Shawangunk conglomerate at Otisville, Orange County, New York, a large fauna of eurypterids has been obtained, but other fossils except Ceratiocaris are absent. Here in the Shawangunk Mountains of Eastern New York is a great series 630 feet thick of the Shawangunk grit resting upon the Hudson River shales. The series consists of alternating shales varying from 2 to 6 inches in thickness, and conglomerates or sandstones from 1 to 50 feet thick, the shale bands containing the merostomes. Some of the specimens though only 2.5 mm. long are perfectly preserved and are by far the youngest and smallest yet recorded. In regard to the occurrence Clarke says: "In the Shawangunk section we have a fauna constantly repeating itself through a thickness of 650 feet which elsewhere appears only and briefly at the base of the Salina" (**36**, 303). The perfect specimens are all of young individuals, adults being represented only by fragments. The species recorded are: 1. *Eurypterus maria* Clarke, 2. *Eusarcus? cicerops* Clarke, 3. *Dolichopterus otisius* Clarke, 4. *D. stylonurus* Clarke and Ruedemann, 5. *Stylonurus* (*Ctenopterus*) *cestrotus* Clarke, 6. *S.* (*Ctenopterus*) sp. α, β, γ, 7. *S. myops* Clarke, 8. S. sp., 9. *Hughmilleria shawangunk* Clarke, 10. *Pterygotus globiceps* Cl. and R.

From the middle part of the Shawangunk grit of Delaware Water Gap, Pennsylvania, intercalated black shales similar to those in New York have furnished eurypterids. These were discovered by Mr. Paul Billingsley of Columbia University, who collected a large amount of material and who reports that the fragments are all dissociated, the carapaces commonly occurring by themselves, and separated from the abdominal segments, as if arranged by violent currents. Professor G. van Ingen and Mr. J. C. Martin have also collected extensively from this section. From their large number of specimens Clarke and Ruedemann have been able to identify Nos. 1, 3, 7, 9, 10 of the list of species recorded from the Shawangunk of Otisville, and they make the comment that "Unfortunately, the maceration, already so prevalent in much of the eurypterid material at Otisville, has at the Delaware Water Gap reached such a destructive degree that the shale is filled with a mass of comminuted eurypterid fragments" (**39**, 417).

Upper Siluric or Monroan. The Bertie waterlime of New York of Upper Monroan age has long been famous for the wonderful eurypterid fauna which it contains. This has been found in two localities: (1) in the quarries in North Buffalo, Erie County, and (2) in Herkimer County; there are scattered occurrences of single species in other localities, which will be referred to below. The quarries at Buffalo have yielded the largest number of remains, the specimens having been sent in great numbers to museums all over the world, and the rock has now been so well worked over that probably no new disclosures will be made. For purposes of study of the entire fauna of the Bertie the large collection in the Museum of the Buffalo Society of Natural Sciences offers excellent opportunities. The Bertie contains the largest eurypterid fauna of any one formation in the world, there being recorded fourteen species (**39**, 89) referred to four genera: Eurypterus (5 sp.), Pterygotus (5 sp.), Eusarcus (1 sp.), and Dolichopterus (3 sp.). The specimens are for the most part astonishingly well preserved, but other organisms are extremely rare. In the Museum above referred to are a few specimens of marine organisms obtained from the formation which furnished the eurypterids. One slab of the waterlime about 1¼ inches thick shows on one side an *Orthoceras undulatum* which is very much worn, the siphuncle being exposed and the surface macerated (No. 13310 E 1639 of Buf. Soc. Nat. Sci. Coll.) and on the other side is a well preserved Eurypterus head (11461 E 976). There is one other specimen of *O. undulatum* (13309, E 1638) of a very carbonaceous nature. There are a number of specimens of *Trochoceras gebhardi*, but as a rule these are found in a rock not of the character typical of the Bertie layers bearing the eurypterids. In one case it is arenaceous and not a calcilutyte (13353 E 1682), containing two fragmentary specimens. The slabs containing the Trochoceras do not have eurypterid remains on them, with one exception (13345 E 1674) in which there is a eurypterid claw on a slab showing an imperfect *T. gebhardi*. Associated with the eurypterids are a number of well preserved gastropod shells belonging to a genus which is also known from the Monroe formation of Michigan. This genus is Hercynella and it is represented at Buffalo by two species *H. patelliformis* O'Connell and *H. buffaloensis* O'Connell (**200**).

Seven specimens of *Lingula sp.* Hall occur on one of the slabs. *Leperditia alta* and a large number of pelecypods of the genus Goniophora, but labeled *Leperditia alta* occur on a slab which probably does not come from the Buffalo region, but is more likely from Ohio, judging from the lithological character. Finally, there are a number of specimens of *Ceratiocaris acuminata* associated on the same slabs with the eurypterids and showing a preservation as perfect as theirs, these being the only fossils which do show this. Number 11453 E 968 contains *Eurypterus lacustris* and a large specimen of *Ceratiocaris acuminata*, the former with head shield and body separated, but both beautifully preserved. The plant remains are important, for many of the specimens of Eurypterus are found lying embedded in *Buthotrephis lesquereuxi*, and in one case there is a large mass of Buthotrephis at the side and on top of a Eurypterus (13329 E 1657). (Some of these specimens of Buthotrephis are now regarded as graptolites.) There are three specimens of the plant ? form, *Chondrites graminiformis*, two of which are excellently preserved (13273 E 1602 and 13312 E 1641 Pohlman's type[4]). At Waterville, Oneida County, New York, a small scorpion *Proscorpius osborni* Whitfield has been found in a good state of preservation in the Bertie waterlime.

A remarkable fact in connection with the occurrence of the eurypterids in the Bertie is their distribution in two distinct basins or "pools," the "Herkimer pool" on the east and the "Buffalo pool" on the west. These pools, while prolific in species and individuals, have, however, only two species in common, so far as published data show. Further search may reveal more forms in common, but it is certainly a significant fact that the abundantly represented species of the two areas are distinct, when the horizon is the same, and the localities only a few hundred miles distant. The following list gives the specimens for each pool, representative or identical species being apposed (**39**, 92 footnote):

Buffalo Pool	*Herkimer Pool*
1. Eurypterus lacustris	1. Eurypterus remipes
2. E. lacustris var. pachychirus	
3. E. pustulosus	
4. Eusarcus scorpionis	
5. Dolichopterus macrochirus	5. Dolichopterus machrochirus
6. D. siluriceps	6. D. testudineus
7. Pterygotus buffaloensis	7. Pterygotus macrophthalmus
8. P. cobbi	8. P. cobbi
9. P. grandis	9. Proscorpius osborni

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[4] Figured in Buf. Soc. Nat. Hist. Bull., Vol. V, p. 31 (220).

"The species common to both are *Dolichopterus macrochirus* and *Pterygotus cobbi*, both of which are quite rare, while the predominant species in both places are unlike. It is not believed that these differences necessarily express distinct stratigraphic horizons, as both lie near the top of the waterlime succession, but rather indicate original regional separation into distinct lagoons or pools . . . . which we may assume to have been synchronous. There is, in the face of the difference suggested, a certain degree of approximation in the two expressed by such vicarious species as *E. remipes* and *E. lacustris*, *P. macrophthalmus* and *P. buffaloensis*, which may well mean distinctions due to geographic isolation. The Herkimer pool is well restricted and its faunule cannot be traced very far towards the west; the Buffalo *E. lacustris*, however, appears alone as far east as Union Springs, Cayuga County, and as far west as Bertie, Ontario. Another difference in these faunas is the preponderating great size of all the species in the Buffalo pool, and, by contrast, the small size of and abundant young among the Herkimer county species; . . . . That the smaller creatures lived in conditions of shallower water is evinced by the sun-dried and cracked rock surfaces of their matrix, while such evidences are wanting in the Buffalo pool . . . . " (**39**, 92). *Eurypterus remipes*, one of the common forms in the Herkimer pool, is also obtained from the Rondout waterlime above the Cobleskill at Seneca Falls, Seneca county, New York.

The Manlius limestone of uppermost Monroan age has yielded fragments of *Eurypterus microphthalmus* from various localities in New York and also from Ohio. The type, a single cephalon, came from a loose boulder near Cazenovia, Madison county, New York, containing also fragments of *Spirifer vanuxemi* from which the age of the boulder was determined. One nearly entire specimen was found in the drift of Onondaga Valley, near Syracuse, New York. Of the number of carapaces now in the New York State Museum, one was collected "in the town of Litchfield in Manlius limestone, not less than 100 feet above the Eurypterus horizon in the Bertie waterlime" (**39**, 194). Professor Whitfield's type of *E. eriensis* (now regarded by Clarke and Ruedemann to be the same as *E. microphthalmus* Hall) came from the hydraulic limestones, the Put-in-Bay dolomite, of Beach Point, Put-in-Bay Island, Lake Erie, Ohio.

There is one more Siluric fauna to be noted and that is the one in the Kokomo waterlime of Indiana. Clarke and Ruedemann, following Schuchert correlate the Kokomo with the Noblesville of

Northern Indiana (Schuchert **255**, 467), which is in turn correlated with the Lockport of New York. The latter correlation may stand, but the former is not supported by palaeontological evidence. In a private communication from E. M. Kindle, who has written quite an extensive paper on the Stratigraphy of the Niagara of Northern Indiana (**139**), the following comment is made in reference to the statement that the Kokomo eurypterids are found in the Lockport-Noblesville horizon: "This reference of course is an unfortunate error and is presumably based upon a correlation of the Kokomo limestone and the Noblesville limestone of Indiana which is undoubtedly erroneous. There is practically nothing in common between the faunas of the Noblesville and the Kokomo. The lithology of the beds is quite as unlike as their faunas so that there is absolutely no ground for correlating these two distinct faunas." Since Kindle has done considerable work in the region and made extensive collections of the fossils, his statement is of importance. Palaeontologically it appears that the Kokomo is surely not earlier than Salinan and is more probably Monroan, corresponding to one of the waterlimes in New York.[5] The eurypterid remains are very thin films, scarcely more than impressions, so that scale markings often are not visible. The preservation is not nearly so perfect as in the Bertie waterlime of New York. There are at least 40 feet of limestone, characterized by thin lamination of bedding planes and the presence of eurypterids. Above this horizon is a series of limestones, not thinly laminated, containing a rather rich brachiopod fauna, but with the eurypterids the only other fossils are ceratiocarids. The brachiopod fauna, so far as is possible to learn from the literature, occurs at a different level from that in which the merostomes are found (Foerste, **67**, 6–8). Four species have been reported from the merostome beds: ***Eurypterus ranilarva*** Cl. and R., ***E.*** (***Onychopterus***) ***kokomoensis*** Miller and Gurley, ***Eusarcus newlini*** (Claypole) and ***Stylonurus*** (***Drepanopterus***) ***longicaudatus*** Cl. and R., giving altogether a fairly large fauna and one that is sufficiently well preserved for purposes of characterization.

DEVONIC. The Devonic of America shows a great decline of the eurypterids, so far as we can judge from the fossil record, for, while in the Siluric there had been an ever-increasing number of species and of individuals, in the Devonic, on the other hand, there are no representatives in the Lower and Middle, and it is not until the very top of the Upper that a few stragglers are found. The first, a specifi-

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[5] The brachiopods described by Foerste have a distinctly Monroan aspect.

cally undetermined Pterygotus mentioned by Billings, is from the Grand Greve limestone of Lower Devonic age. Remains of Pterygotus have also been found in the lower marine Devonic at Dalhousie. Finally, near Campbellton, New Brunswick, "in some indurated limestones containing fish remains of probably Upper Devonic age" are also eurypterid remains which Clarke and Ruedemann have described as *Pterygotus atlanticus*. An extremely incomplete and problematic form is a two-jointed fragment from the lower beds of the Portage sandstones of Italy, Yates County, New York. Originally described by Dawson as a plant (*Equisetides wrightiana* Dawson), it was later placed among the eurypterids by Hall as *Stylonurus* (?) *wrightiana* and is now so recognized by Clarke and Ruedemann. There is but a single fragment, part of a jointed appendage apparently. A number of fragments of Stylonurus, originally described as *Stylonurus excelsior* by Hall and which Beecher used in making the restoration which he called *Stylonurus lacoanus*, have all been united by Clarke and Ruedemann under the species *Stylonurus* (*Ctenopterus*) *excelsior*. There are only two specimens, one a complete carapace from the Catskill beds at Andes, Delaware County, New York, and another more fragmentary carapace from the same formation in Pennsylvania. *Eurypterus beecheri* Hall described from the Chemung of Pennsylvania has proved to be the same as *Stylonurus beecheri*.

MISSISSIPPIC. From the Waverly beds of Warren, Warren County, Pennsylvania, a single eurypterid was described by Hall and Clarke in 1888 as *Eurypteris approximatus*. No complete description of this form is given anywhere, but the figure in the *Palaeontology of New York*, Volume VII, plate 27, figure 6, (**106**), shows the one specimen that has been found in which there are the cephalon and nine somites. This form is regarded by Clarke and Ruedemann as one of several phylogerontic species of Eurypterus which constitute the end members in different lines of development in North America and mark the decline of the race.

CARBONIC. In the Carbonic (Pennsylvanic) are found four species of Eurypterus in Pennsylvania; *Eurypterus* (*Anthraconectes*) *mazonensis* Meek and Worthen (**170**) in the Coal Measures of Mazon Creek, Ill.; two species in the Carbonic of Nebraska, and two doubtful species from St. John, New Brunswick. Particular attention should be called to *Eurypterus* (*Anthraconectes*) *mansfieldi* which C. E. Hall has figured (**98**, pl. IV), showing the form just as it was found lying on ferns in a very perfect state of preservation, in the lower Productive

Coal Measures in Beaver County, Pennsylvania. *Eurypterus stylus* of Hall from the Venango beds is probably the same as *E. (Anthraconectes) mansfieldi*, both type specimens being compressed longitudinally, but otherwise appearing the same. *Eurypterus (Anthraconectes) pennsylvanicus* C. E. Hall described from a single small carapace from Pithole City, Venango County, Pennsylvania is probably allied to *E. mansfieldi*, according to Clarke and Ruedemann (**39**, 428). A few fragments called by Hall *E. ? potens* also occur in Pennsylvania. The Carbonic eurypterids are in productive coal beds associated with plants and land animals. The fauna and flora at Mazon Creek have been especially studied by Meek and Worthen (**170**) from whose report the following associates of *Eurypterus mazonensis* are taken:

A Xiphosuran *Euproöps danae* M. and W.
An isopod *Acanthotelson stimpsoni* M. and W.
  also *A. eveni* M. and W.
Decapoda: *Palaeocaris typus* M. and W.
  Anthrapalaemon gracilis M. and W.
Myriopoda: *Euphoberia armigera* M. and W.
Arachnida: *Pulmonia: Eoscorpius carbonarius* M. and W.
  Mazonia woodiana M. and W.
  Architarbus rotundatus Scudder
Cock-roach: *Mylacris anthracophila* Scudder
Other insects: *Miamia danae* Scudder
  Chrestotes lapidae Scudder

The remains from the Coal Measures of Nebraska were found by Barbour in an outcrop one mile south of Peru in the bluffs facing the Missouri River (**10**). The formations exposed there consist of alternating shale and limestone changing rapidly to a shale which finally merges into a massive sandstone. In this last bed there occurred a shaly band composed of thin, irregularly shaly layers, seldom half an inch thick, alternating with micaceous sand. This whole band was scarcely a foot thick and extended for over three hundred feet. Even within the band it was only the topmost two inches of the shale seams which yielded eurypterid remains. These were found in considerable abundance, forty specimens so far having been obtained in an area of as many square feet. The chitinous shells, probably representing merely the shed exoskeletons, have in all cases been reduced to carbonaceous films, but except where these are very thin they are in a good condition of preservation so that the grosser anatomy and surface markings can be seen and even some of the minute sculpturing.

Barbour has described only one species, *Eurypterus* (*Anthraconectes*) *nebraskensis*. It is represented by a large number of individuals and undoubtedly as the beds are worked over a great many more specimens will be obtained. They are for the most part in good condition, though seemingly representing only the exuviæ. The individuals are small, averaging two inches in length, the largest not being even three inches long. Barbour figures and describes, but does not name a second form which he thinks may be a species different from *E. nebraskensis*.

The faunal associates listed by Barbour are: "innumerable leaves, stems and fragments of certain land plants, conspicuously Neuropteris pinnules, stems of Calamites, and leaf-whorls of Asterophyllites . . . . Intimately associated with the eurypterids were considerable amounts of actual plant tissue, preserved as such since Carboniferous times." (**10**, 507–8).

Two species, *Eurypterus ? pulicaris* Salter from the Little River plant bed no. 2 of St. John, New Brunswick, and *Eurypterella ornata* Matthew are so doubtfully identified that Clarke and Ruedemann do not consider even their eurypterid origin as certain. (**39**, 93) The horizon at which they were found was originally supposed to be Devonic, but is now known to be Carbonic.

GREAT BRITAIN

SILURIC. *Lower Siluric Llandovery-Wenlock*. The earliest eurypterid remains that have been found anywhere outside of North America, are the fragments of *Pterygotus problematicus* from the May Hill sandstone of upper Llandovery age, found in Eastnor Park near Ledbury, Herefordshire, England. A single chelate appendage was found associated with *Nucula eastnori*, Pentameri and Stricklandiniae. The Mayhill sandstone is a basal one resting by overlap upon various earlier members of the series even upon the Shineton (Dictyonema) shales at Wenlock Edge. There is everywhere a marked break and unconformity between the underlying beds and the May Hill sandstone, indicating that the latter was laid down by an advancing sea, if it was not a terrestrial (fluviatile) sandstone reworked by the sea.

In the Wenlock of the Pentland Hills, Scotland, occurs the first large eurypterid fauna of Europe. The rock containing the eurypterids is "an irregularly fissile, fine-grained sandstone, containing a considerable amount of structureless carbonaceous matter distributed in thin layers" (Laurie, **145,** 151). The only other fossil which Malcolm Laurie found in the rock at the time of his first discovery was *Dictyocaris ramsayi*, but since then Peach and Horne have made a large collection of other types. In 1898 Laurie added some new discoveries from Gutterford Burn, and among these the one specimen of a scorpion, much crushed and lying imbedded in the carbonaceous matter. In the Pentland Hills the Wenlock formation is a yellowish sandstone and conglomerate, showing cross-bedding and in some places ripple marks, and is exposed in several inliers in the Old Red Sandstone, later formations having been eroded. Extensive collections have been made here by Henderson, Brown and Laurie, the latter describing a number of new species. One of the best sections is seen along Gutterford Burn, a tributary of the Esk, where the following specimens have been collected, the determinations having been made by Laurie.

Bembicosoma pomphicus Laurie.
Stylonurus (Drepanopterus) pentlandicus (Laurie).
S. (Drepanopterus) bembicoides (Laurie).
S. (Drepanopterus) lobatus (Laurie).
Eurypterus conicus Laurie.
E. minor Laurie.
Eusarcus scoticus (Laurie).
Eurypterus 3 sp. undet.
Stylonurus elegans Laurie.
S. macrophthalmus Laurie.
S. ornatus Laurie.
Slimonia dubia Laurie.
Dictyocaris ramsayi Salter.
Palaeophonus loudonensis Laurie.

Upper Siluric or Ludlow. The Ludlow of England has yielded eight species of eurypterids all in a most fragmentary condition, making it difficult to determine forms accurately. They all come from the Ludlow outcrops in Shropshire and Herefordshire. From the Aymestry limestone there are some remains which have been doubtfully referred to *Pterygotus problematicus*. This same species appears again and again throughout the remainder of the Siluric, being rare in the Upper Ludlow group, but becoming more common towards the top of the Temeside group in the Ludlow district. *Eurypterus acuminatus* Salt. and *E. linearis* are rare in the Upper Ludlow, the former occurring also in the Temeside group. *Eurypterus pygmæus* Salt. and *Stylonurus megalops* Salt. are common as fragments in the higher olive shales of the Temeside group. *Pterygotus banksii* Salt. together with numerous indeterminable species of Eurypterus are found in the Ludlow Bone-Bed; this species is also common in the Platyschisma bed and the upper olive shales of the Temeside group; in the same shale *P. ludensis* Salt. is abundant. In all cases where species are reported to be common it is to be remembered that no entire specimens are found but only fragments and *disjecta membra.* The occurrences cited are from the Ludlow district in Shropshire; to the southwest in the Downton Castle sandstone at Kington in Herefordshire *Pterygotus banksii* has been found in large numbers associated with *P. gigas,* the spines of crustacea and fish and also *Platyschisma helicites* and *Lingula cornea.* Salter has further described *Eurypterus abbreviatus* from a single telson which he found at Kington. Brodie collected specimens of *Pterygotus banksii*, *Eurypterus pygmaeus*, *E. acuminatus*, and *E. abbreviatus* at Purton, Herefordshire. The greatest abundance of specimens is found in a sandy marl lying just below a yellow sandstone containing plants, seed-vessels of Lycopodiaceae and fragments of eurypterids. The horizon is about that of the Ludlow Bone-Bed (**24**, 236).

The Ludlow of Scotland is found only in a few inliers in Lanarkshire. Division 3 recognized by Peach and Horne (**215**) consists of flagstone and greywackes with Ceratiocaris beds and containing the Ludlow fish band. From these beds *Slimonia acuminata* Salter has been described associated with five species of Ceratiocaris and worm tracks. From the same shales *Pterygotus bilobus* Salter and the common Ludlow fish *Thelodus scoticus* are reported. In certain places occur *Beyrichia kloedeni* and *Platyschisma helicites* forms very frequently associated with Upper Siluric eurypterids. The fish band contains *Slimonia acuminata*, the myriopod *Archidesmus loganensis* Peach, four species of the phyllocarid crustacean Ceratiocaris and one of Physocaris, together with numerous fish fragments and two species of Thelodus. Of great interest has been the discovery by Peach in this fish band of one of the oldest scorpions from Great Britain, *Palaeophonus caledonicus* Hunter. This is approximately the same horizon at which Lindström found *Palaeophonus nuncius* in Gotland (see below, p. 34). The eurypterid horizon par excellence occurs in the next higher division above the fish band and contains *Eurypterus lanceolatus* (Salt.), *Eusarcus obesus* (Woodw.), *E. scorpioides* (Woodw.), *Pterygotus bilobus* Salt., together with three varieties of this species, *P. raniceps* (Woodw.), *Slimonia acuminata* (Salt.) and *Stylonurus logani* (Woodw.). The Pterygotus beds are followed by the "Trochus," more properly, Platyschisma beds which correspond to the beds of the same name in England, and which contain fragments of *Slimonia acuminata* as do the next overlying beds which mark the transition into the sandy Lanarkian series.

The Lanarkian. About 1400 to 1500 feet above the base of this series occurs a fish-band in the carbonaceous shales of which *Eurypterus dolichoschelus* (Laurie) has been found associated with Ceratiocaris, five species of fishes, and Pachytheca and Parka. At another locality seven species of fishes, Ceratiocaris, Dictyocaris, Pachytheca, a Myriopod and *Eurypterus dolichoschelus* (Laurie) and *Stylonurus ornatus* (Laurie) have been found.

DEVONIC. The Devonic formations of Great Britain have a better representation of eurypterids than have those of North America. The Old Red Sandstone of Forfarshire has yielded *Pterygotus anglicus* in abundance and in a good state of preservation and one nearly entire specimen of *P. minor*. From the same region come three species of *Stylonurus*, *S. scoticus*, *S. powriei*, *S. ensiformis*, and finally the little known *Eurypterus brewsteri*. In the Old Red Sandstones of England occur *Eurypterus pygmaeus and Stylonurus symondsii.* Fragments of *Pterygotus problematicus* have been reported from the Lower Old Red of the Ludlow district. A few fragments of *Eurypterus hibernicus* Baily have been found in the Upper Old Red of Kiltorcan, Kilkenny County, Ireland. There are thus ten species of eurypterids from the Devonic of Great Britain, all occurring in the Old Red Sandstone facies of deposits associated with fishes, land plants, fluviatile molluscs, myriopods and crustacea, such as the fresh or brackish-water phyllopod, Estheria, the ostracod Beyrichia and certain phyllocarids. With the exception of *Pterygotus anglicus* none of the eurypterids is either abundant or well preserved, most of the species being represented by a single portion of the exoskeleton or by a number of fragments. Moreover, these fragments are scattered in occurrence geologically and geographically. Six species are found in Forfarshire, Scotland, in the Lower Devonic (Caledonian); three species are sparingly represented in Brecknockshire and Herefordshire, England, at the same horizon; while a few fragments of a single species occur in the Upper Old Red of Ireland.

MISSISSIPPIC OR CALCIFEROUS. The Calciferous fresh-water limestone of Scotland, equivalent in age to the Mississippic of North America, has yielded three species of Eurypterus: *scabrosus*, Woodward, *scouleri* Hibbert and ? *stevensoni* Ethridge. Of the first species a doubtful fragment has been reported from Eskdale, Scotland. Hibbert was the first to describe as a Eurypterus the two nearly complete individuals and three or four fragments found in the Burdiehouse fresh-water limestone at Kirkton, near Bathgate, West Lothian. The organic remains are scattered through in no regular order and are not confined to the limestone particularly, but occur in the sandy beds above and below, not in particular seams. One of the eurypterid remains had earlier been described under the name *Eidothea*, but Hibbert rightfully called it *Eurypterus scouleri* (**116**, 280, 281, pl. XII). Vegetal matter is diffused through the limestone and in this fossil plants are well preserved, the form particularly abundant being *Sphenopteris affinis*. Microscopic Entomostraca abound which have been named by Hibbert *Cypris scoto-burdigalensis*, and a microscopic mollusc approaching Planorbis also occurs. Fish remains are abundant: *Gyracanthus formosus* Agassiz, ganoid and sauroid teeth, and many coprolites are found. Woodward says of this limestone: "it is a fresh water deposit, and abounds in bands of silex alternating with calcareous matter and presents all the appearance of having been deposited by thermal waters during the Carboniferous epoch" (**312**, 180). The third species above referred to was described by Etheridge from a few fragmentary spines found in a light-colored micaceous sandstone of the Cement-stone group in Kimmerghame quarry, near Dunse in Berwickshire, Scotland. In the same shire Peach has recently discovered some fragments for which he erected the genus Glyptoscorpius, a eurypterid which had combs, and walking feet ending in two claws. In the Calciferous sandstone here at Lennel Braes, near Coldstream, Berwickshire, a specimen of *G. perornatus* Peach showing five body segments much broken, and a number of combs, referred to *G. caledonicus* (Salter) have been found. Besides these, are a number of fragments referred to the genus Glyptoscorpius, but specifically unidentifiable (**209**, 516–525). At the River Esk, four miles south of Langholm, Dumfriesshire, the two species of Glyptoscorpius are found with the following associates: several species of Phyllocarida, *Ceratiocaris scorpioides* Peach, *C. elongatus* Peach; Peracarida, *Anthrapalaemon etheridgei* Peach, *A. parki* Peach, *A. traquairii* Peach, *A. macconochii*, *A. formosus* Peach, *Palaeocrangon eskdalensis* Peach, *Palaeocaris scoticus* Peach, and later discoveries have added *Pseudo-Galathea rotundata* and *Palaeocrangon elegans.* At Tweeden Burn, Liddesdale, have been found many *membra disiecta,* unidentifiable. The fauna also includes some Xiphosurans: *Prestwichia alternata* Peach from Lavuston Burn, upper Liddesdale, *Prestwichia rotundata* Woodward from the River Esk locality and *Cyclus testudo* Peach from Langholm. Many of these crustacean forms are quite well preserved. Scorpions also occur at Langholm: *Eoscorpius glaber* Peach, *E. euglyptus* Peach and *E. inflatus* Peach. These forms though never perfect are very complete and show all parts well.

CARBONIC OR CARBONIFEROUS. In the Coal Measures of Great Britain the final stragglers among the eurypterids are found, just as they are in North America. *Eurypterus* (*Arthropleura*) *mammatus* Salter includes fragments from Pendleton Colliery, near Manchester, England, which are associated with many plant remains, a few of which may be mentioned:

Lepidodendron obovatum.
Lepidodendron sternbergii.
Lepidodendron elegans.
Neuropteris loshii.
Neuropteris heterophylla.
Neuropteris gigantea.
Cyclopteris flabellata.
Sphenopteris obtusiloba.
Sphenopteris latifolia.
and some others

BOHEMIA

SILURIC. *Lower Siluric Ee$_1$, Ee$_2$ of Barrande.* From the Siluric basin of Bohemia Barrande listed six species of Pterygotus, all of which are represented by the merest fragments and are of rare occurrence. They are found in undoubted marine formations, for Ee$_1$ is a black graptolite-bearing shale, while Ee$_2$ contains numerous cephalopods, gastropods, trilobites and corals (12, 39–44). The species of Pterygotus are: *bohemicus, comes, cyrtochela, kopaninensis, mediocris and nobilis.* Of the general preservation and faunal associates of these eurypterids Barrande remarks:

"Our basin, so privileged in respect to the frequency and the state of preservation of the trilobites and the other crustacea, appears, on the contrary, very poor in the fossils representing the two types of eurypterids, which are recognized in our formations. (Pterygotus and Eurypterus).

". . . . Far from finding individuals complete and well preserved, it will prove difficult to add any new facts of importance to those already published on the organization of the species of this type.

"That advantage is not reserved for us, for the Silurian basin of Bohemia, so favored in all other respects, is relatively poor in fossils of the genus Pterygotus, not only because of their great rarity, but also because of the reduction of the specimens to little fragments. Since almost all of the remains are found in the large horizon of the Cephalopods, that is, in our limestone band e 2, it seems to us that one may attribute the almost total disappearance of these gigantic Crustacea to the voracity of these molluscs, against whom they were forced to maintain the struggle for existence." (13, 556).

We need not consider seriously this interpretation of the fragmental character of the eurypterid remains as they can be interpreted in another manner (see p. 199).

Semper (261) has recently done some work in the region and has revised and added to Barrande's original species. In e_1 β at Podol Dvorce, near Prague, he has collected a few fragments to which he has given the name *Pterygotus barrandei* of which there are also some fragments at Dlouhá hora, in horizon e_2. A few endognathites from the former locality have been described as *P. beraunensis* Semper, since they come from near Beraun. Some fragments of a swimming foot are also described by Semper from e_2, as *P. blahai*, in a thinly laminated limestone rich in Orthoceras which occurs at Višňovka near Lochhov. Of all the species found in Bohemia the best one is a fragmentary individual showing the head with the first eight somites attached, and a few separate fragments, these constituting the species *Eurypterus acrocephalus* Semper from horizon e_1, at Dvorce. From these various occurrences it is apparent that the eurypterids, though represented by a large number of species in the beds of Wenlock or Niagaran age of Bohemia, are found only rarely and in a most fragmentary condition, although the large marine fauna occurring in the same horizon is one of the largest and most perfect that is known, forming the basis for Barrande's ponderous work on the *Système Silurienne* in which many volumes are devoted to the description and figuring of the marine fossils, while a very little space suffices for the meagre eurypterid fauna. Barrande notices in a paper on the correlation of the Siluric deposits of Bohemia and Scandinavia (*Parallele entre les Depôts Siluriens de Bohême et de Scandinavie* (**11**), that Pterygotus remains have been found at Klinta in Scania, southern Sweden, which recall *Pterygotus problematicus* of England (**11**, 58)

Upper Siluric or Ff$_1$ *of Barrande.* Two species of Eurypterus have been recorded from the Upper Siluric of Bohemia in the same incomplete condition that those from the Lower were found in. *E. pugio* Barrande and a species related to *P. bohemicus* Barrande are the only representatives in this period. The latter is reported by Semper from a single claw and part of an abdomen found at Cerná rockle, Kosoř in a black limestone of Ff$_1$ age.

CARBONIC. *Coal Measures of Bohemia.* In a rather blackish grey shale at Wilkischen, near Pilsen, Reuss found two macerated, but nearly complete individuals and a cephalon of a eurypterid which he named *Eurypterus imhofi*, and which is associated on the same slab with pinnules of Pecopteris. Reuss says that this fossil "of the Bohemian Coal Measures—a freshwater formation— is without doubt derived from a freshwater or brackish water ancestor (**228**, 83)."

BELGIUM

DEVONIC. *Upper Devonic.* In only one locality in Belgium have eurypterids been found. Some thirty kilometers southwest of Liege at Pont de Bonne near Modave is exposed a section showing the Upper Devonic sandstones of Condroz. Lohest, Braconier and Destinez in working up this section found a few eurypterid fragments in 1888 and in the following year these were described by Julien Fraipont and Maximin Lohest. *Eurypterus lohesti* was described by Dewalque from two specimens, one the counterpart of the other, representing a complete cephalon. Fraipont described *Eurypterus ? dewalquei* from a cephalon, a portion of an abdominal segment, and a few other fragments. One other fragment, a portion of one of the appendages, is thought by Fraipont to belong to a species related to *E. ? dewalquei*, but because of the similarity in ornamentation and agreement in size, he makes it only a variety, calling it *E. ? dewalquei var. longimanus.*

. The beds in which these remains were found are described by Lohest as follows (**68**, 55):

"We procured the major part of our fossils from the bed of green shales. They contain: *Glyptolepis multistriatus, G. radians, Holop-*

tychius dewalquei, Eurypterus, Spirorbis. Mr. Destinez found a beautiful Ichthyolite which is probably new. We cite again: lamellibranchs, lingulas, ferns and Lepidodendron. That bed contains sometimes thin layers of sandstones, on which one finds associated on the same planes of stratification lingulas, lamellibranchs, ferns, and ganoid scales. Mr. I. Braconier has collected excellent specimens which demonstrate the certainty of this fact.[6] . . . .

"In beds F, G, H, I, we have not collected any determinable fossils; but in the lower part of bed J we have found vegetal matter, scales of the fish, *Holoptychius inflexus*, a small species of Pterichthys and the remains of a Dipterus as I have pointed out." (Fraipont, **68**, 55).

A little lower in the series in bed B impressions have been found which suggest those of rain-drops, also very numerous axes of vegetal matter probably, as suggested by Mr. Mourlon, stipes of the fern *Palaeopteris hibernica*, and in the same bed Mr. Destinez found a large bone, belonging apparently to a fish.

BALTIC ISLES AND RUSSIA

SILURIC. *Upper Siluric of Gotland.* The Baltic Isles have long been famous for their Siluric sections which are so excellently shown on Gotland. The lowest eurypterid horizon is found in the *Pterygotus marl* of Gotland of Upper Siluric age. Although the sections in the northern and southern parts of the island have been studied separately and the correlations are not as yet complete, still one important fact has stood out for the whole island: there is everywhere a great break between the Lower and Upper Gotlandian (Siluric), indicating in many places that there was at this time a retreat and a subsequent advance of the sea. In the north around Visby, Hedström (**113**) has recognized seven subdivisions of the Gotlandian. Beginning at the base, the first bed to be shown along the shore is the Stricklandia marl (I of Hedström), with Palæocyclus as the characteristic fossil. Then follows II, a marly limestone showing reef masses at intervals and containing a Niagaran fauna. The succeeding beds (III) are of particular interest to us. At the base are 3 meters of yellowish grey limestone with crinoids, and then follow 16 meters of grey marls interstratified with limestone, the upper 5 meters of which consist of stratified limestones, oolitic at the base, but becoming gradually coarser towards the top where they are conglomeratic, and where

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[6] M. I. Braconier a recueilli de superbes échantillons qui demontrent ce fait a l'évidence."

ripple-mark structures are sometimes observable. Above these strata comes a complex of layers, one meter thick, consisting of marl shales and limestones with *Pterygotus osiliensis* and *Palæophonus nuncius*, a scorpion. Lindström has called this thin stratum the *Pterygotus marl*, and it is seen to lie just at the top of III.[7] Here there is a break and disconformity, above which follows a conglomerate (IV) with waterworn gastropoda and portions of *Spongiostroma holmi* Rothpletz. The relations of the reef limestone and marl are well shown in the vicinity of Visby. The reefs are composed of non-stratified accumulations of Stromatoporæ mainly, with a few corals in addition. Between the reefs of II are the finely stratified bituminous, brownish shales of III, well shown on the island of Karlsö west of Visby, which contain a marine and estuarine fauna mixed.

Upper Siluric of Oesel. This island has yielded a large crustacean fauna in the usual association with eurypterids. Two species of Eurypterus are reported: *E. laticeps* Schmidt from two fairly perfect head shields, and *E. fischeri* Eichwald from many excellent specimens. There is also an abundance of fragments of *Pterygotus osiliensis*. The bed in which these occur is a fine grained Platten-kalk or dolomite, with a peculiar fauna throughout; this is followed by other granular limestones containing the usual uppermost Siluric fauna. The Eurypterus beds have a fairly wide extent in western Oesel, but the fullest development of the fauna is seen only near Rootziküll, on the west coast of the island, in the parish of Kielkond. Here the beds are a dolomite in which the chitinous exoskeletons of Pterygotus and Eurypterus have been excellently preserved, and even the tail sting of a Ceratiocaris and the shields of two cephalaspid fishes, *Thyestes verrucosus* Eichw. and *Tremataspis schrenckii* Schmidt, and the shells of the little *Lingula nana* Eichw. have been found. Rather rarely occurring are the Hemiaspidae: *Bunodes lunula* Eichw., *B. rugosus* Nieszk. and *schrenckii* Nieszk. sp. as well as *Pseudoniscus aculeatus* Nieszk. and the shells of *Orthoceras tenue* Eichw. Bunodes and Leperditia are represented by many specimens, but these and all the other fossils mentioned show, in place of the shell which is destroyed, only a black carbonaceous film representing the organic material (Schmidt **248**, 28). The eurypterids do not show the same kind of preservation, for Schrenck (**254**, 35) reports the integuments of *Eurypterus remipes* Dekay (with which *E. tetragonophthalmus* Fischer is synonymous and which Schmidt has since placed under *E. fischeri*,) to be entirely unaltered, not only chemically, still remain-

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[7] Professor Grabau has argued that this bed should be placed in the Upper Gotlandian.

ing pure chitin, but also in their entire internal make-up and with their original color such as is characteristic of living representatives.

AUSTRO-RUSSIAN BORDER LANDS

SILURIC. *Upper Siluric of Podolia and Galicia.* From various localities, mainly in Galicia, Austria, but occasionally from Podolia, Russia, a few fragments of *Eurypterus fischeri* are reported, together with specimens determined with difficulty to be *Pterygotus osiliensis*, and also three telsons of specifically unidentifiable Stylonurus.

DEVONIC. *Middle Devonic of Galicia.* A single telson of a Pterygotus species has been found by Siemiradzki in the Devonic coral limestone of Skala, Valencia (263).

AUSTRALIA

SILURIC. *Upper Siluric.* Professor McCoy has reported (168) the finding by Mr. F. Spry of four eurypterid remains in the Upper Silurian rocks underlying Melbourne. These rocks have been correlated by McCoy with the Victorian series. The matrix in which the merostome fragments were found is described as resembling very closely the black flaggy layers of the uppermost Ludlow of Lesmahagow, Scotland, while the eurypterid found there seems to have its closest affinities to *Pterygotus bilobus.* The specimen figured is fragmentary, but apparently of a eurypterid, which McCoy has referred to *Pterygotus australis.*

GERMANY

CARBONIC. *Middle Saarbrücker.* In the Saarbrücken "basin" of Germany the Carbonic has been divided into two parts, the upper or Ottweiler with grey and red sandstone at the top and grey shale and sandstone below containing *Pecopteris arborensis*, Estheria, *Leaia baentschiana* and fish remains; and the lower or coal-bearing Saarbrücken beds containing in their middle members abundant plant remains and two eurypterid species. *Arthropleura armata* Jordan is represented by two or three abdominal segments found in the beds in the Friedrichsthal tunnel two miles from Saarbrücken, where in the same beds are plant remains of *Lepidophyllum lineare* Brong., and *Anthracosaurus raniceps*, *Dictyoneura blattina* and other insects. In the railroad shaft at Jägersfreude, ¾ of a mile from Saarbrücken, one incomplete individual of a form called by Jordan *Adelopthalmus* (*Eurypterus*) *granosus* has been found (135).

SOUTH AMERICA

CARBONIC. *Coal Measures of Brazil.* David White described some fragments from the Santa Catharina system, about 55 meters above the granite floor (Tubarão series) or 225 meters below the Iraty black shale (Passa Dois series) northeast of Minas, Santa Catharina, Brazil (**297,** 229, 589, 605). The fragments are of most doubtful identification, some being apparently plant remains, but others having a suggestion of relation to the Eurypterida (**297,** pl. XI, figs. 4, 6, 7, 8). These are described as *Hastimima whitei* White.

AFRICA

DEVONIC. *Witteberg series.* From the Upper Devonic Witteberg series of Cape Colony, South Africa, Professor A. C. Seward has described two fragments of a fossil which he considers to be a eurypterid. He compared it with the species described by David White from Brazil and called it Hastimima sp., saying: "The view which seems to me most hopeful is that this fossil represents part of a body-segment of a Eurypterid" (**262,** 485). Seward sent the specimens to Woodward who not only concurred in the opinion as to the eurypterid nature of the remains, but he also considers that the Brazilian forms are eurypterids (**325,** 486). It is gratifying to note that the opinion expressed by these earlier writers is fully supported by Clarke and Ruedemann in their monograph where they have discussed this genus (**39,** 400–406) and figured some more of the fragments from Brazil.

The Witteberg series consists of a hard blue micaceous quartzite, replaced in some localities by shale or slate. So far as known it is unfossiliferous except for occasional plant stems allied to Lepidodendron and the widespread markings known as *Spirophyton caudagalli.* A photograph of this fossil given by Hatch and Corstorphine in their *Geology of South Africa* (**111,** fig. 22.) reveals no essential difference between it and the *Spirophyton caudagalli* of the Esopus, Oriskany and Hamilton of eastern North America. Seward considers that it is an inorganic structure and Grabau has gone even further in suggesting that it is due to the blowing back and forth of reed-like plants on a plastic surface capable of holding such markings long enough until covered over by wind-blown dust or sand. At any rate, the formation is undoubtedly non-marine, and the two eurypterid fragments therein could hardly have come from any other source than the land waters.

PORTUGAL

PERMIC. About a third of the way south from Porto to Lisbon and about 40 km. in from the coast lies Bussaco, famous for its Carboniferous rocks and the abundant flora therein. This region was studied as long ago as 1850 by Carlos Ribeiro. Three years later a symposium on the sections and fossils of Bussaco appeared in the *Quarterly Journal of the Geological Society of London*, and then in 1890 Wenceslau de Lima made a very complete study of the region, with the result that, after a careful identification of the flora, he was able to show that certain of the beds are Permic in age, belonging to the lower Rothliegende. During his investigations he found a single small eurypterid, the cephalon, body segments and telson intact, though all of the appendages are missing. The animal measures 32.5 mm. in length, has a large cephalon, a bulging body made up of seven somites and a long tail formed by the last seven segments. To this form he gave the name *Eurypterus douvillei*. Associated with this eurypterid are the plants *Walchia piniformis* and *Sphenophyllum thoni*. The beds in which these fossils are found are a series of shales, sandstones and conglomerates from the abundance of which de Lima argues that torrential conditions must have obtained at the end of the Carbonic and beginning of the Permic (**149**, 151). A glance at Koken's world map showing the relation of land to sea during the Permic will show that Bussaco was in position to receive very heavy torrential deposits, being near the coast of that time.

SUMMARY TABLES

All of the data of the foregoing pages are summarized in the following series of tables. Table I is designed to show quickly in what horizons and country any species of eurypterid has been found. Table II, summarizing Table I, gives at a glance the numbers of species that are recorded from each horizon and from each country and also from each period. Table III gives in greater detail the localities in which remains have been found, but is particularly meant to give an accurate description of the mode of occurrence of every species, if the remains are fragmentary, to state how many fragments have been found, and if perfect to record with equal care the numbers found. Each table is complete in itself, but all three, on the other hand, should be used together since each one supplements the others.

TABLE III

Summary of the Distribution, Facies and Mode of Occurrence of the Eurypterida

SPECIES	HORIZON AND FACIES	LOCALITY	CONDITION
1. Beltina danai	Greyson shales, Belt Terrane	Montana	Hundreds of fragments; surface markings absent generally.
	Altyn limestone	Altyn, Montana; Johnson Creek, Alberta, Canada	Numerous fragments, some showing scale markings
2. Bembicosoma pomphicus	Wenlock shales and sandstones	Gutterford Burn, Pentland Hills, Edinburghshire, Scotland.	Two incomplete individuals
3. Dolichopterus breviceps	Normanskill shales and sandstones	Broom Street Quarry, Catskill, New York	A single carapace
4. D. frankfortensis	Schenectady shale	Schenectady (Dettbarn Quarry), Aqueduct, Rotterdam Junction Duanesberg, New York	About a dozen carapaces
5. D. laticeps	Zone K, Eurypterus waterlimes of Oesel	Rootziküll, Oesel	Two head shields
6. D. latifrons	Schenectady shale	Schenectady, New York	Two incomplete carapaces
7. D. macrochirus	Bertie waterlime	Williamsville, Litchfield, Waterville, New York	Three nearly complete individuals; a few fragments
8. D. otisius	Black shales in Shawangunk grit	Otisville, New York	About 30 carapaces some showing two attached tergites
		Delaware Water Gap, Pa.	A number of carapaces
9. D. siluriceps	Bertie waterlime	Williamsville, New York	A single carapace
10. D. stylonuroides	Black shales in Shawangunk grit	Otisville, New York	Three carapaces, and one specimen with carapace, swimming leg and three tergites
11. D. (?) testudineus	Bertie waterlime	Litchfield Herkimer Co., New York	A single carapace
12. Echinognathus clevelandi	Utica shale	Holland Patent, Oneida Co., New York	Fragment of a thoracic segment
13. Eurypterus abbreviatus	Downton Castle sandstone	Kington, Herefordshire, England	One incomplete telson
14. E. acuminatus	Spirifer elevata shales, Upper Ludlow group Olive shales of Temeside group	Ludlow railroad cut, Ludlow, Shropshire, England	Several incomplete telsons and rare fragments
15. E. approximatus	Waverly	3 mi. s. of Warren, Warren Co., Pennsylvania	A single specimen with carapace and nine somites

16. E brewsteri	Arbroath flags, Caledonian Old Red Sandstone	Kelly Den, near Arbroath, Forfarshire, Scotland	A carapace, portion of first thoracic segment; ovisac
17. E. brodiei	Lower part of Downton Castle sandstone	Purton, near Stoke Edith, Herefordshire, England	One almost entire individual and some fragments
18. E. cephalaspis	Downton sandstone	Kendal, Westmoreland, England	
19. E. chadwicki	Normanskill shales and sandstones	Broom Street Quarry, Catskill, New York	A single carapace
20. E. conicus	Wenlock shales and sandstones	Gutterford Burn, Pentland Hills, Edinburghshire, Scotland	A number of more or less complete individuals; limbs fragmentary.
21. E. cyclophthalmus	Wenlock shales and Sandstones	Gutterford Burn, Pentland Hills, Edinburghshire, Scotland	One specimen showing part of carapace and parts of all body segments
22. E. dekayi	Bertie waterlime	Near Buffalo, New York	Two nearly complete specimens
23. E. ? dewalquei	Famennian sandstone	Condroz, Belgium	Portion of cephalothorax and a few fragments
24. E. ? dewalquei var. longimanus	Famennian sandstone	Condroz, Belgium	Last segment of an appendage
25. E. dolichoschelus	Ludlow fish band	Dippal Burn, Greenock Burn, etc., Lesmahagow, Lanarkshire, Scotland	Numerous fragments
	Glauconome shale in div. 9, P & H.	Hagshaw Hills, Lanarkshire, Scotland	
	Lanarkian, div. 9, Peach& Horne	Dippal Burn, Lesmahagow, Scotland	
26. E. douvillei	Rothliegende sandstone	Bussaco, Portugal	One almost complete individual, well preserved, appendages absent
27. E. fischeri	Zone K Eurypterus waterlimes of Oesel	Rootziküll, Wita, Attel, etc. Oesel	Large numbers preserved entire with unaltered chitin.
	Zone K Eurypterus waterlimes of Oesel	Lodjal, S. E. Oesel	Traces
	Upper Siluric limestone of Podolia	Kamieniec podolski, Dumanow, Zawale, Studzienica, Zalucza, all in Podolia	Fragments only
28. E. fischeri var. rectangularis	Zone K Eurypterus waterlimes of Oesel	Rootziküll, Oesel	Occasional incomplete specimens; carapace with two tergites and 2 appendages
29. E. hibernicus	Kiltorcan sandstones and flagstone, Upper Old Red	Kiltorcan, Kilkenny Co., Ireland	Nearly a dozen fragments, including 2 carapaces, 2 or 3 somites, fragments of appendages
30. E. imhofi	Roof shale in Carbonic of Bohemia	Wilkischen, near Pilsen, Bohemia	Several nearly entire individuals; well preserved

TABLE III—Continued

SPECIES	HORIZON AND FACIES	LOCALITY	CONDITION
31. E. lacustris	Bertie waterlime	Williamsville and Buffalo, New York; Bertie, Ontario	Well preserved specimens abundant
		Black Rock, Erie Co., Union Springs, Cayuga Co., New York	A few smaller specimens
32. E. lacustris var. pachychirus	Bertie waterlime	Buffalo, Erie Co., New York	An abdomen, two swimming legs several endognathites
33. E. lanceolatus	Pterygotus bed, div. 4 of Ludlow (Peach & Horne)	Lesmahagow, Lanarkshire, Scotland	Several nearly entire individuals and fragments
34. E. liniaris	Spirifer elevata shales, Upper Ludlow group	Ludford, S. of Ludlow, and Kington, Herefordshire	Telsons only
35. E. lohesti	Famennian sandstone	Condroz, Belgium	One carapace
36. E. maria	Black shales in Shawangunk grit	Otisville, Orange Co., New York	Abundant, well preserved, though incomplete; mostly immature; carapaces numerous
		Delaware Water Gap, Pa	Several carapaces
	Olive shales in Tuscarora sandstone	Swatora Gap, Pa.	Several small carapaces
37. E. microphthalmus	Manlius limestone	Cazenovia, Madison Co.; Onondaga Valley, Litchfield, Jerusalem Hill, Herkimer Co.	One nearly complete and many cephala
	Monroe (Put-in-Bay) limestone	Put-in-Bay Island, Lake Erie	Two cephala
38. E. minor	Wenlock shales and sandstones	Gutterford Burn, Pentland Hills, Edinburghshire, Scotland	One nearly entire individual, a carapace and fragments
39. E. moyseyi	Clay nodules in Coal measures	Northwest Ilkeston, Derbyshire, England	Two specimens, posterior abdominal segments missing
40. E. pittsfordensis	Pittsford shale	Pittsford, Monroe Co., New York	Rare and fragmentary; a few nearly complete individuals
41. E. pristinus	Schenectady shale	Dettbarn Quarry, Schenectady, New York	One carpace and doubtful patches
42. E. ? (Dolichopterus?) prominens	Clinton sandstones	Cayuga Co., New York	A single carapace
43. E. pustulosus	Bertie waterlime	Buffalo, New York	Two carapaces and one postabdomen, all fragmentary

44. E. pygmaeus	Downton Castle sandstone	Kington, Herefordshire, England	Carapace and portion of body; scattered fragments
	Olive shales, Temeside group	Ludford Lane and Ludlow railroad cut, Herefordshire, England	Fragmentary individuals common
45. E. ranilarva	Kokomo waterlime	Kokomo, Indiana	A few nearly complete; rare and poorly preserved
46. E. remipes	Bertie waterlime	Waterville, town of Westmoreland, Oneida Co.; Jerusalem (Wheelock's Hill, Litchfield, Herkimer Co.; Cedarville and Paris Hill, Herkimer Co.; near Oriskany, Cayuga junction, Cayuga Co., N. Y.	Numerous well preserved and many fragments
	Rondout waterlime	Seneca Falls, Seneca Co., New York	Typical specimens well preserved
47. E. ruedemanni	Schenectady shales	Near Rotterdam Junction, Schenectady Co., New York	A single carapace
48. E. scouleri	Burdie House limestone	Kirkton, near Bathgate Linlithgowshire, Scotland	Two carapaces and a few fragmentary abdomina
	Upper Old Red Sandstone	Kiltorcan, Kilkenny Co., Ireland	Three patches of integument; very doubtful
49. E. cf scouleri	Coal Measures of Silesia	Near Neurode, County of Glatz, Silesia	One incomplete carapace and two fragments of appendages
50. E. ? (Dolichopterus?) stellatus	Schenectady shales	Dettbarn Quarry, Schenectady, New York	Incomplete carapace and patches of integument
51. E. ? stevensoni	Cement stone group lowest Calciferous	Kimmerghame Quarry, Blackadder Water, near Dunce, Berwickshire, Scotland	Three fragments of body segments showing sculpturing
52. E. wilsoni	Downton sandstones	Ludlow's Pit, Radstock, Somersetshire, England	First six body segments only
53. E. sp. Barbour	Coal measures	One mile south of Peru, Nebraska	One almost complete individual
54. E. sp. Elles and Slater	Chonetes striatella beds Ludlow Bone-Bed Downton Castle sandstones Temeside shales	Ludlow district, Shrophire and Herefordshire	Various unidentifiable fragments probably representing several species of Eurypterus; rare in two lower horizons, common in the two higher
55. E. sp. Peach and Horne	Wenlock shales and sandstones	Near Straiton, Girvan, Scotland	Fragments

TABLE III—Continued

SPECIES	HORIZON AND FACIES	LOCALITY	CONDITION
56. E. sp. Laurie	Wenlock shales and sandstones	Gutterford Burn, Pentland Hills, Edinburghshire, Scotland	Numerous unidentifiable fragments
57. E. sp. (?) Laurie			
58. E. sp. Moberg	Ove l-Ramsåsa formation Zone 1	Bjersjölagård, Sweden	Abundant fragments
59. E. (Adelopthalmus) granosus	Middle Saarbrücker Schiefer	RR. shaft at Jägersfreude, ¾ mi. from Saarbrücken, Germany	One incomplete individual
60. E. (Anthraconectes) mansfieldi	Carbonic shale below Darlington cannel coal	Near Cannelton, Darlington Township, Beaver Co., Pennsylvania	Several nearly complete and a number of fragments
61. E. (Anthraconectes) mazonensis	Coal Measures (Alleghany)	Mazon Creek, Grundy Co., Illinois	Single ventral impression of incomplete individual
62. E. (Anthraconectes) nebraskensis	Coal measures	One mile south of Peru, Nebraska	Abundant and well preserved; some only carbonaceous films
63. E. (Anthraconectes) pennsylvanicus	Arenaceous shale in Coal Measures	Rooker Farm, Pithole City, Venango Co., Pennsylvania	A single small carapace
64. E. (Onychopterus) kokomoensis	Kokomo waterlime	Kokomo, Indiana	One nearly perfect and well preserved; three fairly good specimens
65. E. (Tylopterus) boylei	Guelph dolomite	Ontario, Canada	A single incomplete though well preserved individual
66. Eusarcus acrocephalus	Ee_1 Kuchelbader graptolite sh.	Dvorec, near Prague, Bohemia	Carapace and first eight body segments; better preserved than other specimens in same bed
67. E. (?) cicerops	Black shales in Shawangunk grit	Otisville, New York	Rare; several carapaces and a pre-abdomen
68. E. linguatus	Normanskill shales and sandstones	Broom Street Quarry, Catskill, New York	Two fragmentary carapaces
69. E. logani	Eramosa beds, Niagaran	Eramosa river, near Guelph, Ontario, Canada	Numerous fragments very poorly preserved; post-abdominal segments, spines, telsons, a metastoma

70. E. (?) longiceps	Schenectady shale	Schenectady, New York	A number of carapaces; one with fragmentary preabdomen attached
71. E. newlini	Kokomo waterlime	Kokomo, Indiana	Four nearly complete, poorly preserved, showing later growth stage
72. ? E. obesus	Trochus or Platyschisma beds (5 of Peach and Horne)	Lesmahagow, Lanarkshire	One almost entire, and fragments
73. E. punctatus	Upper Ludlow	Whitcliff, near Ludlow, Herefordshire, Kendal. Westmoreland, England	Detached appendages and fragmentary remains Five abdominal segments and fragments
	Lower Ludlow	Church Hill, Leintwardine, Shropshire, England	
	Wenlock limestone and shale	Dudley, Worcestershire, England	
74. E. aff. punctatus et acrocephalus	Ee₁ β Kuchelbader graptolite shales	Podol Dvorce, Bohemia	A single endognath
75. E. raniceps	Div. 3 (Peach and Horne) Ceratiocaris beds	Logan water, near Lesmahagow, Lanarkshire, Scotland	One incomplete and fragmentary individual
76. E. scorpioides	Div. 3 (Peach and Horne) Ceratiocaris beds	Logan water, near Lesmahagow, Lanarkshire. Scotland	One nearly complete individual
77. E. scorpionis	Bertie waterlime	Williamsville and Buffalo, New York	Twenty specimens, 7 nearly entire, one of a young individual
78. E. scoticus	Wenlock shales and sandstones	Gutterford Burn, Pentland Hills, Edinburghshire, Scotland	Numerous fragments
79. E. simonsoni	Zone K, Eurypterus waterlimes of Oesel	Quarry at Wita, near Rootziküll, Oesel	One incomplete individual and one fragment of a foot
80. E. triangulatus	Schenectady shale	Dettbarn Quarry, Schenectady, New York	Three incomplete specimens, 3 carapaces, one preabdomen
81. E. vaningeni	Dark shales 21 feet below base of Vernon shales	Near Farmer's Mills, Oriskany Creek, 3 mi. S. of Clinton, New York	Two carapaces; a few fragments, and one carapace with nearly complete preabdomen
82. Glyptoscorpius caledonicus	Calciferous sandstone	Lennel Braes, Coldstream and Cockburnspath, Berwickshire, Scotland	Combs only
83. G. peronatus	Calciferous sandstone	River Esk, 4 mi. S. of Langholm, Dumfriesshire, Scotland	Carapaces with 5 body segments attached; specimen incomplete
84. Hastimima whitei	Santa Catharina system	N. E. of Minas, Santa Catharina, Brazil	Three fragments of integument showing surface markings
85. H. sp. Seward	Witteberg shales	Cape Colony, South Africa	One fragment of body segment showing surface markings

TABLE III—Continued

SPECIES	HORIZON AND FACIES	LOCALITY	CONDITION
86. Hughmilleria magna.............	Schenectady shale	Dettbarn Quarry, Schenectady Co., New York	Carapaces abundant; portions of abdomen fragmentary; preservation poor
		Duanesburg and Rotterdam Junction, Schoharie Co., New York	A few carapaces
87. H. shawangunk.................	Black shales in Shawangunk grit	Otisville, New York	Very abundant; most nepionic forms
		Delaware Water Gap, Pennsylvania	Several macerated carapaces; one segment showing sculpture
	Olive shales in Tuscarora sandstone	Swatora Gap, Pennsylvania	Several small carapaces
88. H. socialis.......................	Pittsford shale	Pittsford, Monroe Co., New York	Very abundant; entire individuals rather rare
89. H. socialis var. robusta...........	Pittsford shale	Pittsford, Monroe Co., New York	One nearly entire abdomen; two somites; an imperfect metastoma
90. H. cf. socialis....................	Keefer sandstone, base of Salina	Pennsylvania—Maryland border	Numerous fragments badly crushed, difficult of identification
91. Megalograptus welchi............	Liberty limestone, middle Richmond	Near Clarkesville, Clinton Co., Ohio	Two fragmentary endognaths, one postabdominal somite
92. Strabops thacheri...............	Potosi limestone	Flat River, St. François Co., Missouri	One nearly perfect specimen
93. Pterygotus anglicus...........	Tealing beds, Pterygotus beds of Carmylie, Acanthodian beds of Turin Hill, the Arbroath flags etc. all of the Caledonian Old Red Sandstone series	Babruddy, Perthshire; Leysmill near Arbroath, Turin Hills, near Reswallie, Tealing and Carmylie, and elsewhere in Forfarshire, Scotland	Many nearly complete individuals and numerous *disjecta membra*
94. P. arcuatus.....................	Lower Ludlow	Leintwardine, Shropshire, England	A body segment, two endognaths and some fragments
95. P. atlanticus....................	Dalhousie limestone (Campbellton beds)	Campbellton, New Brunswick	Three specimens: a free chela, coxa of a swimming leg, and a small portion of a metastoma
96. P. australis.....................	Upper Siluric flags (Victorian series)	Melbourne, Australia	Four fragments
97. P. barrandei..................	Ee_1 β Kuchelbader graptolite shales	Podol Dvorce, near Prague, Bohemia	A few fragments
	Ee_2 β Budňaner limestone	Podol Dvorce, Dlouhá hora, Bohemia	
98. P. beraunensis..................	Ee_1 β Kuchelbader graptolite sh.	Podol Dvorce, near Prague, Bohemia	A few endognaths only

99. P. bilobus var. acidens	Divisions 3 and 4 (Peach and Horne) i.e. the Ceratiocaris and Pterygotus beds of the Ludlow	Lesmahagow, Lanarkshire, Scotland	One antenna, one cephalon, and nearly all the segments of one individual
100. P. bilobus var. crassus			At least one perfect specimen
101. P. bilobus var. inornatus			Many perfect fragments all altered by pressure
102. P. bilobus var. perornatus			An almost entire individual and several incomplete carapaces
103. P. blahai	Ee_2 Budňaner limestone	Višňovka near Lochkov, Bohemia	Broken fragments of swimming foot
104. P. bohemicus	Ee_1 β Kuchelbader graptolite shales	Dvorec	Fragments only
	Ee_2 Budňaner limestone	Near Budnian, below Karlstein; Dlouhá hora near Karlstein, Bohemia	Fragments only
105. P. aff. bohemicus	Ff_1 Lochkover limestone	Černá rokle near Kosor, Bohemia	A single claw and part of an abdomen
106. P. buffaloensis	Bertie waterlime	Buffalo, New York	A few nearly perfect individuals and several fragments
107. P. cobbi	Bertie waterlime	Near Buffalo, New York	Two rami of the chelate appendage
108. P. cobbi var. juvenis	Bertie waterlime	Schorley's Farm, Litchfield, Herkimer Co., New York	Two nearly entire specimens
109. P. fissus	Ee_2 Budňaner limestone	Dlouhá hora, near Karlstein, Bohemia	A single claw
110. P. gigas	Downton Castle sandstones	Kington Herefordshire	Fragments numerous
	Downton Castle sandstones (massive sandstone bed)	Ludlow district, Herefordshire and and Shropshire, England	Fragments rare
	Olive shales and Temeside Bone-Bed in Temeside group	Ludlow district, Herefordshire and Shropshire, England	Fragments common
111. P. kopaninensis	Ee_2 Budňaner limestone	Near Kopanina, Bohemia	Rare and incomplete fragments
112. P. ludensis	Downton Castle sandstones	Ludlow district Herefordshire and Shropshire, England	Fragments rare
	Olive shales and Temeside Bone-Bed, Temeside group	Ludlow district Herefordshire and Shropshire, England	Fragments common
	Transition beds to Old Red	Trimpley, near Kidderminster, Herefordshire, England	One specimen with nearly all of body somites and telson; a few other fragments
113. P. macrophthalmus	Bertie waterlime	Williamsville, Erie Co.; Litchfield, Herkimer Co.; Waterville, Oneida Co., New York	Three nearly perfect specimens and a few fragments

TABLE III—Continued

SPECIES	HORIZON AND FACIES	LOCALITY	CONDITION
114. P. minor	Indurated shale overlying Arbroath flags	Farnell, Forfarshire, Scotland	One small almost perfect specimen
115. P. monroensis	Pittsford shale	Pittsford, Monroe Co., New York	One cephalothoracic shield
116. P. (Eusarcus ?) nasutus	Normanskill shale	Broom Street Quarry, Catskill, New York	Several carapaces
	Schenectady shale	Schenectady, Aqueduct, and Duanesburg, Schenectady Co., New York	Several carapaces
117. P. nobilis	Ee$_1$ β Kuchelbader graptolite shales	Podol Dvorce, Bohemia	Fragments only
	Ee$_2$ Budňaner limestone	Near Kolednik Bohemia	
118. P. normanskillensis	Normanskill shale	Broom Street Quarry, Catskill, New York	Carapaces; possibly some telsons
119. P. problematicus	May Hill sandstone	Abelish, Eastnor Park, near Ledbury, Herefordshire	Chela only
	Throughout entire Upper Ludlow group	At Whitcliff and many localities in and near Ludlow, Herefordshire	Fragments rare
	Platyschisma beds, Temeside group	Ludlow district	Fragments abundant, but poorly preserved. No entire individuals
	Downton Castle sandstones, Temeside group	Bradnor Hill, Kington, and near Ludlow, Herefordshire	
	Olive shales, Upper Temeside group	Ludlow district	
	Temeside Bone-Bed	Ludlow district	
120. P. cf. problematicus Salter (Semper)	Ee$_2$ Budňaner limestone	Kolednik Bohemia	A single fragment of a chela
121. P. prolificus	Schenectady shales	Schenectady, Aqueduct, Rotterdam Junction, Duanesburg, Schoharie Junction. Uly Crreek, New York	A number of fairly complete carapaces
122. P. ? stylops	Downton Castle sandstones	Kington, Herefordshire, England	Anterior portion of a single carapace
123. P. taurinus	Ledbury shales	Ewyas Harold, Herefordshire	A nearly complete carapace, portions of telson and body segment, and fragments
124. P. sp. Siemiradzki	Devonic limestone	Skala, Podolia	A single telson

125. P. sp. H. Woodw.	Knoydart formation	McArras Brook, Antigonish Co., Nova Scotia	Specifically indeterminable fragments
126. P. (Erettopterus) banksii	Ludlow Bone-Bed	Ludlow	Many specimens, none complete; fragments abundant
	Platyschisma-beds in Temeside group	Ludlow	
	Downton Castle sandstones	Ludlow Lane, Whitcliffe, Parlan, exterior slope of Woolhope Valley, Kington, Herefordshire	
	Olive shales, Upper Temeside group	Ludlow England	
127. P. (Erettopterus) globiceps	Shales in the Shawangunk grit	Otisville, New York	No entire specimens; several carapaces, a few body segments, a swimming leg several telsons; four immature individuals
	Shales in Tuscarora sandstone	Swatora Gap, Pa	Several small carapaces
128. P. (Erettopterus) cf. globiceps	Shales in the Shawangunk grit	Delaware Water Gap, Pennsylvania	A small distorted carapace
129. P. (Erettopterus) grandis	Bertie watertime	Buffalo, New York	A single telson
130. P. (Erettopterus) osiliensis	Zone K, Eurypterus waterlimes of Oesel	Rootziküll, Oesel	Many separated members; no entire individuals
	Pterygotus marl	Visby, Gotland	Fragmentary, but abundant
	Transition beds to Devonic of Galicia	Zalesczyki, Galicia	Fragments, determined with difficulty
131. Slimonia acuminata	Div. 3, 4, 5 & 6 (Peach and Horne), Ludlow	Banks of Logan Water, Lesmahagow, Lanarkshire	One nearly perfect specimen; dismembered organs abundant
132. S. cf. acuminata (Seemann)	Ee₂ Budňaner limestone	Dlouhá hora, Bohemia	One fragment of an ectognath
133. S. dubia	Wenlock shale and sandstone	Gutterford Burn, Pentland Hills, Edinburghshire, Scotland	Badly preserved carapace and parts of first eleven somites
134. Stylonurus beecheri	Chemung sandstones	Warren, Warren Co., Pennsylvania	One incomplete individual
135. S. ensiformis	Turin beds, Caledonian Old Red Sandstone	Turin Hill Quarries, near Reswallie, Forfarshire	A single incomplete telson
136. S. ? limbatus	Schenectady shale	Schenectady and Duanesburg, Schenectady Co., New York	Six carapaces, two doubtfully identified
137. S. logani	Pterygotus beds, div. 4 (Peach and Horne)	Logan Water, Lesmahagow, Lanarkshire	One incomplete specimen, showing carapace, ten body segments and a few appendages
138. S. macrophthalmus	Wenlock shales and sandstones	Gutterford Burn, Pentland Hills, Edinburghshire, Scotland	One complete individual; several fragments

TABLE III—Continued

SPECIES	HORIZON AND FACIES	LOCALITY	CONDITION
114. P. minor	Indurated shale overlying Arbroath flags	Farnell, Forfarshire, Scotland	One small almost perfect specimen
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116. P. (Eusarcus ?) nasutus	Normanskill shale	Broom Street Quarry, Catskill, New York	Several carapaces
	Schenectady shale	Schenectady, Aqueduct, and Duanesburg, Schenectady Co., New York	Several carapaces
117. P. nobilis	Ee$_1$ β Kuchelbader graptolite shales	Podol Dvorce, Bohemia	Fragments only
	Ee$_2$ Budňaner limestone	Near Kolednik Bohemia	
118. P. normanskillensis	Normanskill shale	Broom Street Quarry, Catskill, New York	Carapaces; possibly some telsons
119. P. problematicus	May Hill sandstone	Abelish, Eastnor Park, near Ledbury, Herefordshire	Chela only
	Throughout entire Upper Ludlow group	At Whitcliff and many localities in and near Ludlow, Herefordshire	Fragments rare
	Platyschisma beds, Temeside group	Ludlow district	Fragments abundant, but poorly preserved. No entire individuals
	Downton Castle sandstones, Temeside group	Bradnor Hill, Kington, and near Ludlow, Herefordshire	
	Olive shales, Upper Temeside group	Ludlow district	
	Temeside Bone-Bed	Ludlow district	
120. P. cf. problematicus Salter (Semper)	Ee$_2$ Budňaner limestone	Kolednik Bohemia	A single fragment of a chela
121. P. prolificus	Schenectady shales	Schenectady, Aqueduct, Rotterdam Junction, Duanesburg, Schoharie Junction. Uly Crreek, New York	A number of fairly complete carapaces
122. P. ? stylops	Downton Castle sandstones	Kington, Herefordshire, England	Anterior portion of a single carapace
123. P. taurinus	Ledbury shales	Ewyas Harold, Herefordshire	A nearly complete carapace, portions of telson and body segment, and fragments
124. P. sp. Siemiradzki	Devonic limestone	Skala, Podolia	A single telson

125. P. sp. H. Woodw.	Knoydart formation	McArras Brook, Antigonish Co., Nova Scotia	Specifically indeterminable fragments
126. P. (Erettopterus) banksii	Ludlow Bone-Bed	Ludlow	Many specimens, none complete; fragments abundant
	Platyschisma-beds in Temeside group	Ludlow	
	Downton Castle sandstones	Ludlow Lane, Whitcliffe, Parlan, exterior slope of Woolhope Valley, Kington, Herefordshire	
	Olive shales, Upper Temeside group	Ludlow England	
127. P. (Erettopterus) globiceps	Shales in the Shawangunk grit	Otisville, New York	No entire specimens; several carapaces, a few body segments, a swimming leg several telsons; four immature individuals
	Shales in Tuscarora sandstone	Swatora Gap, Pa	Several small carapaces
128. P. (Erettopterus) cf. globiceps	Shales in the Shawangunk grit	Delaware Water Gap, Pennsylvania	A small distorted carapace
129. P. (Erettopterus) grandis	Bertie watertime	Buffalo, New York	A single telson
130. P. (Erettopterus) osiliensis	Zone K, Eurypterus waterlimes of Oesel	Rootzikülll, Oesel	Many separated members; no entire individuals
	Pterygotus marl	Visby, Gotland	Fragmentary, but abundant
	Transition beds to Devonic of Galicia	Zalesczyki, Galicia	Fragments, determined with difficulty
131. Slimonia acuminata	Div. 3, 4, 5 & 6 (Peach and Horne), Ludlow	Banks of Logan Water, Lesmahagow, Lanarkshire	One nearly perfect specimen; dismembered organs abundant
132. S. cf. acuminata (Seemann)	Ee$_2$ Budňaner limestone	Dlouhá hora, Bohemia	One fragment of an ectognath
133. S. dubia	Wenlock shale and sandstone	Gutterford Burn, Pentland Hills, Edinburghshire, Scotland	Badly preserved carapace and parts of first eleven somites
134. Stylonurus beecheri	Chemung sandstones	Warren, Warren Co., Pennsylvania	One incomplete individual
135. S. ensiformis	Turin beds, Caledonian Old Red Sandstone	Turin Hill Quarries, near Reswallie, Forfarshire	A single incomplete telson
136. S. ? limbatus	Schenectady shale	Schenectady and Duanesburg, Schenectady Co., New York	Six carapaces, two doubtfully identified
137. S. logani	Pterygotus beds, div. 4 (Peach and Horne)	Logan Water, Lesmahagow, Lanarkshire	One incomplete specimen, showing carapace, ten body segments and a few appendages
138. S. macrophthalmus	Wenlock shales and sandstones	Gutterford Burn, Pentland Hills, Edinburghshire, Scotland	One complete individual; several fragments

TABLE III—Continued

SPECIES	HORIZON AND FACIES	LOCALITY	CONDITION
139. S. megaolps	Olive shales, Temeside group	Ludlow railroad cut, Herefordshire	Fragments common, carapaces especially, but all broken
140. S. modestus	Normanskill shale	Broom Street Quarry, Catskill, New York	Several small carapaces, portions of the abdomen, a leg
141. S. myops	Shales in the Shawangunk grit	Otisville, New York	One entire individual poorly preserved; numerous carapaces; some with attached somites
		Delaware Water Gap, Pennsylvania	Several large and small carapaces
142. S. ornatus	Wenlock shales and sandstones	Gutterford Burn, Pentland Hills, Scotland	Three or four fragments including portions of carapace, abdomen, appendages and telson
143. S. powriei	Turin beds, Caldeonian Old Red Sandstone	Turin Hills, near Pitscandly, Forfarshire, Scotland	One nearly complete individual
144. S. symondsii	Cornstones middle Old Red	Rowlestone, south of Hay, Brecknockshire, England	One well preserved carapace
145. S. (?) scabrosus	Calciferous shales	Glencartholm, Eskdale, Scotland	One incomplete specimen, showing cephalon, portions of first 10 somites and fragments of appendages
	Lower Carbonic shales and clay iron stones	Sedgley, near Dudley, Staffordshire, England	One incomplete individual with some of the appendages attached
146. S. ? wrightianus	Portage sandstones	Italy, Yates Co., New York	A single, two-jointed fragment; may be part of appendage
147. S. (Ctenopterus) cestrotus	Shales in Shawangunk grit	Otisville, New York	Rare form; a few nearly complete individuals; a few carapaces
148. S. (Ctenopterus) elegans	Wenlock shales and sandstones	Gutterford Burn, Pentland Hills, Scotland	Five fragmentary specimens certainly, two more probably
149. S. (Ctenopterus) excelsior	Catskill sandstone	Andes, Delaware Co., New York	External mold of complete carapace
		Wyoming Co., New York	Fragmentary carapace
150. S (Ctenopterus) multispinosus	Pittsford black shale	Pittsford, Monroe Co., New York	Six incomplete endognathites and one somite

151. S. (Drepanopterus) bembicoides	Wenlock shales and sandstones	Gutterford Burn, Pentland Hills, Scotland	Two incomplete specimens
152. S. (Drepanopterus) lobatus	Wenlock shales and sandstones	Gutterford Burn, Pentland Hills, Scotland	One nearly complete individual, two or three fragments
153. S. (Drepanopterus) longicaudatus	Kokomo waterlime	Kokomo, Indiana	Form not described
154. S. (Drepanopterus) pentlandicus	Wenlock shales and sandstones	Gutterford Burn, Pentland Hills	Several nearly perfect and two fragmentary individuals
155. S. (Tarsopterus) scoticus	Caldeonian Old Red Sandstone	Montroman Muir, near the Forfar and Montrose Pike, Forfarshire	One carapace and an almost entire individual
156. S. sp α Clarke and Ruedemann	Shales in Shawangunk grit	Otisville, New York	Two fragments of leg joints of uncertain specific relations
157. S. sp. β Clarke and Ruedemann	Shales in Shawangunk grit	Otisville, New York	Terminal joints of leg
158. S. sp. γ Clarke and Ruedemann	Shales in Shawangunk grit	Otisville, New York	Fragments of segment and of integument
159. S. sp. δ Clarke and Ruedemann	Shales in Shawangunk grit	Otisville, New York	

SYNONYMY

In order to facilitate the use of the preceding tables, I shall give here a synonymy which is not complete, but is intended only for the convenience of anyone looking for a species which has been revised, and which would not appear under the genus to which it was originally ascribed. Such a synonymy is particularly necessary for species described in foreign literature. Most of the revisions have been made by Clarke and Ruedemann for American and some European species, by H. Woodward for species in Great Britain, by Semper for those in Bohemia originally described by Barrande, and by numerous other writers who have revised only single species.

Original Name	*Present Name or Status*
Adelopthalmus granosus Jordan	Eurypterus (Adelopthalmus) granosus (Jordan)
Carcinosoma newlini Claypole	Eusarcus newlini (Claypole)
C. ingens Claypole	Eusarcus newlini (Claypole)
Ceratiocaris grandis Pohlman	Pterygotus (Erettopterus) grandis (Pohlman)
Dolichocephala lacoana Claypole	Stylonurus (Ctenopterus) excelsior Hall
D. macrocheirus Hall	Dolichopterus macrochirus Hall
D. mansfieldi C. E. Hall	Eurypterus (Anthraconectes) mansfieldi (C. E. Hall)
Drepanopterus bembycoides Laurie	Drepanopterus bembicoides Laurie
D. bembicoides Laurie	Stylonurus (Drepanopterus) bembicoides (Laurie)
D. lobatus Laurie	Stylonurus (Drepanopterus) lobatus (Laurie)
D. longicaudatus Clarke and Reudemann	Stylonurus (Drepanopterus) longicaudatus (Laurie)
D. pentlandicus Laurie	Stylonurus (Drepanopterus) pentlandicus (Laurie)
Echinocaris wrightiana Jones and Woodward	Stylonurus (?) wrightianus (Dawson)
E. wrightiana Etheridge, Woodward and Jones	Stylonurus (?) wrightianus (Dawson)
Eurypterus acrocephalus Semper	Eusarcus acrocephalus (Semper)
E. beecheri Hall	Stylonurus beecheri (Hall)
E. beecheri Hall and Clarke	Stylonurus beecheri (Hall)
E. chartarius Salter	Eurypterus lanceolatus Salter
E. ? cicerops Clarke	Eusarcus (?) cicerops Clarke
E. eriensis Whitfield	Eurypterus microphthalmus Hall
E. giganteus Pohlman	Eurypterus pustulosus Hall
E. lacustris Hibbert	Eurypterus lacustris Harlan
E. lacustris Hall var pachychirus Hall	Eurypterus pachychirus Hall
E. laticeps Schmidt	Dolichopterus laticeps (Schmidt)

Original Name	*Present Name or Status*
E. mansfieldi James Hall	Eurypterus (Anthraconectes) mansfieldi (C. E. Hall)
E. (Arthropleura) mammatus Salter	Not a eurypterid
E. maria (in part) Clarke	Pterygotus (Erettopterus) globiceps Clarke and Ruedemann
E. megalops Clarke and Ruedemann	E. ruedemanni O'Connell
E. megalops Salter	Stylonurus megalops (Salter)
E. pennsylvanicus James Hall	Eurypterus (Anthraconectes) pennsylvanicus C. E. Hall
E. obesus H. Woodward	Eusarcus obesus (H. Woodward)
E. myops Clarke	Stylonurus myops Clarke
Cf. E. potens James Hall	Eurypterus
E. pugio Barrande	Doubtful determination, no standing
E. punctatus H. Woodward	Eusarcus punctatus (Salt.)
E. punctatus Salter	Eusarcus punctatus (Salt.)
E. aff. punctatus Woodw. et acrocephalus Semper	Eusarcus punctatus (Salt.)
E. remipes Logan	Eurypterus lacustris Harlan
E. remipes Bronn and Roemer	Eurypterus lacustris Harlan
E. scoticus Laurie	Eusarcus scoticus (Laurie)
E. scouleri (?) Salter	Eurypterus hibernicus (Baily)
E. simonsoni Schmidt	Eusarcus simonsoni (Schmidt)
E. scorpioides H. Woodw	Eusarcus scorpioides (H. Woodw.)
E. stylus James Hall	Eurypterus (Anthraconectes) mansfieldi (C. E. Hall)
E. symondsii Salter	Stylonurus symondsii (Salter)
E. tetragonophthalmus Fischer	Eurypterus fischeri Eichwald
Eurysoma newlini Claypole	Eusarcus newlini (Claypole)
Eusarcus grandis Grote and Pitt	Eusarcus scorpionis Grote and Pitt
E. scorpionis Pohlman 1881	Eusarcus scorpionis G & P *not* E. scorpionis Pohlman 1886
E. scorpionis Semper	Eusarcus scorpionis G & P
E. scorpionis Seeman	Eusarcus scorpionis G & P
Equisetides wrightiana Dawson	Stylonurus (?) wrightianus (Dawson)
E. wrightiana Wright	Stylonurus (?) wrightianus (Dawson)
Himantoperusa cuminatus Salter	Slimonia acuminata (Salter)
H. acuminatus D. Page	Slimonia acuminata (Salter)
H. bilobus Salter	Pterygotus bilobus var. inornatus (Salter)
H. banksii Salter	Pterygotus (Erettopterus) banksii (Salter)
H. lanceolatus Salter	Eurypterus lanceolatus (Salter)
H. maximus Salter	Slimonia acuminata (Salter)
H. perornatus Salter	Pterygotus bilobus var. perornatus Woodw.
Pterygotus acuminatus Salter	Slimonia acuminata (Salter)

Original Name	*Present Name or Status*
P. acuticaudatus Pohlman	Pterygotus buffaloensis (Pohlman)
P. banksii Salter	P. (Erettopterus) banksii Salter
P. buffaloensis Pohlman	P. buffaloensis (Pohlman)
P. cobbi (P. cummingsi) Semper	P. cobbi Hall
P. comes Barrande	P. bohemicus Barrande
? P. cummingsi Grote and Pitt	P. buffaloensis (Pohlman)
P. cummingsi Grote and Pitt	P. cobbi Hall
P. cyrtochela Barrande	Doubtfully identified, no standing
P. expectatus Barrande	Doubtfully identified, no standing
P. globicaudatus Pohlman	Eurypterus pustulosus Hall
P. globicaudatus Laurie	Eurypterus pustulosus Hall
P. hibernicus Baily	Eurypterus hibernicus (Baily)
P. macrophthalmus ? Pohlman	P. buffaloensis (Pohlman)
P. mediocris Barrande	Doubtfully identified, no standing
P. osborni Hall	Pterygotus macrophthalmus Hall
P. perornatus Salter	P. bilobus var. perornatus Woodw.
P. perornatus var. plicatissimus	P. bilobus var. perornatus Woodw.
P. problematicus Agassiz	P. problematicus Salter
P. problematicus Banks	P. gigas Salter
P. problematicus Strickland and Salter	P. problematicus Salter
P. punctatus Salter	Eusarcus punctatus (Salter)
P. pugio Barrande	Doubtfully identified, no standing
P. quadricaudatus Pohlman	Pterygotus buffaloensis (Pohlman)
P. raniceps (Woodw.)	Eusarcus raniceps (Woodw.)
P. sp. Whiteaves	P. atlanticus Clarke and Ruedemann
? P. sp. Sarle	P. monroensis Sarle

CHAPTER II

A RÉSUMÉ OF THE OPINIONS ON THE HABITAT OF THE EURYPTERIDA

From 1818 when the first Eurypterus was discovered in America by Dr. S. L. Mitchell until 1900, the order of the Eurypterida was held to be made up of marine organisms. This belief in the marine habitat of the oldest Arthropoda known suddenly became the centre of contention at the beginning of the present century in spite of its long period of security. As soon as geologists considered the possibility of origins other than marine for conglomerates, shales and even limestones, there arose discussion as to the nature of the beds in which eurypterids had been found and opinions were perceived to be divergent. It is of interest, then, to take up a systematic review of the literature for the last hundred years and to note what has been the general opinion of geologists and palaeontologists about the bionomy of the eurypterids, and to note also the change from an unquestioning assumption that the habitat was marine, to doubt and finally to opposition to the old idea.

Mitchell considered the form which he found in Westmoreland, New York, to be the impression of a catfish and so placed it under the genus Silurus, noting that the nearest living relative was the electrical silure of the Nile (**180**). He had no idea of the great age of the fossil, but supposed it to have been the remains of a fish which had lived in the Mohawk which was then generally believed to have been dammed so that the river waters and their fauna spread over a wide area. It is curious to see that the first man to find a eurypterid should, without any clear idea of its age or its true nature, have supposed that it lived in a river. This was mere speculation on his part and of no real significance. In 1825, however, Dekay, recognizing its true relation to the arthropods, established a new genus, Eurypterus, for it. He considered it most nearly related to the genera Apus, Binoculus and Lepidurus among modern forms, and placed it with the crustaceans of the order Branchiopoda. He mentions no other fossil associates, nor does he make any statement concerning the habitat, but he evidently considered it marine, for had he not, it is only natural to suppose that he would have made some statement to that effect, since it would have been a new and, indeed, a startling idea to advance. In 1841 Conrad, writing of the Eurypterus from the Bertie says (**44**, 38): "It has been suggested that this genus was of fresh water origin, but the presence of fucoids in the same stratum where the Eurypterus occurs, and the absence of the slightest evidence of a fresh water deposit in any part of the Silurian system, leave no room to doubt that this singular crustacean inhabited the sea." Conrad did not state who the bold spirit was that made such an original suggestion and his reasons for rejecting this explanation are unconvincing, because so-called *fucoids* are not necessarily marine, and non-marine deposits are now extensively known from the Siluric. Furthermore, even if the "fucoids" prove to be graptolites, as now claimed by Ruedemann, a non-marine habitat for the Eurypterus is not precluded. All the early writers seem to have agreed to consign the eurypterids to the class of the Crustacea, and to maintain for them a marine habitat. It has taken many years of patient labor for the students of the anatomy of these organisms and of the taxonomic relations of the Eurypterida to the Crustacea, to Limulus and to the scorpions, to convince the geological world that the Eurypterida are not Crustacea, but belong to the class Arachnida. The work has only just begun of convincing that same geological world that the habitat never was marine, but always fluviatile.

For nearly fifty years after Conrad made his statement authors described new species, erected new genera and worked out the affinities of the eurypterids to Limulus, but they gave not a thought to the habitat. It was not until 1889 that a direct reference was again made to the habitat. In Nicholson and Lydekker's *Manual of Paleontology* (**196**) we find the statement that "the nature of the deposits in which the remains of the Eurypterids are found, and of the fossils associated with them, would prove that these animals were essentially marine, their habits, probably being very similar to those of the existing King-crabs. It is, however, possible that certain of the Eurypterids were inhabitants of brackish or even of purely fresh waters" (**196**, 544).

In 1893, Malcolm Laurie, studying the eurypterid remains in the "Upper Silurian" of Scotland, i.e. the Siluric as generally used in America, found in those rocks of the Pentland Hills only one other fossil, *Dictyocaris ramsayi*, a crustacean (?) (**144**). The large eyes in most of the eurypterids which he found caused him to think that they must in some way be due to the conditions under which the creatures lived, and from a comparison with recent forms he was led to believe that the eurypterids lived in deep water, whether marine or not he does not say, but the former seems to be implied.

Amadeus W. Grabau writing in 1898 of the eurypterids said: "these crustacea were undoubtedly marine" (**81**, 362) thus accepting the usual classification and also the current opinion as to the habitat. On the other hand, Frech (**70**) at about the same time, said that the most evident proof of the retreat of the sea in the formation of the Old Red sandstone in England was the appearance in the Devonic of the eurypterids from the Baltic. This marks the beginning of the change in ideas and embodies the first statement contrary to the prevailing opinion that the habitat of the eurypterids was marine.

The period during which it was either tacitly assumed or definitely stated that these extinct merostomes had lived in the sea was thus brought to a close. There had been a few hints of a possible non-marine existence, but on the whole geologists and palaeontologists had for eighty years been agreed upon the marine habitat.

With the beginning of the new century we find a radical and sudden change of opinion. Chamberlin in his paper on "The Habitat of the Early Vertebrates" gives a philosophical discussion of the question which is extremely interesting and suggestive, though not backed up by much data. He calls attention to the fact that eurypterids and fishes are found associated in the Ludlow (Upper Siluric) of England, in the Island of Oesel in the Russian Baltic, in Podolia, Russia, in Galicia, and in the Waterlime group of North America. "The physical conditions in all these cases seem to have been peculiar," he continues, "and in the case of the Waterlime group they were singularly so, for they permitted a host of these large Eurypterids and other Crustaceans to flourish in seeming luxuriance, while only a meagre and pauperate marine fauna found an occasional entrance into the series. The conditions seem to have been congenial to the fish and Eurypterids, but not to a typical marine fauna" (32, 401, 402). The association of eurypterids and fishes in the Old Red sandstone where marine life was only occasional and meagre does not, as Chamberlin points out, imply prevalent marine conditions, for the Old Red and its homologues are the deposits of fresh water, and yet both the fishes and eurypterids found congenial conditions of life there. Chamberlin, recalling that fishes and eurypterids are found both earlier and later than the Devonic in marine deposits, puts the following question: "Were the fishes and eurypterids primarily marine and later became adapted to fresh water, or were they primarily fresh water forms which were occasionally carried out to sea and which later became adapted to salt water?" He reminds us that we are always in the habit of considering all life at first marine, then terrestrial, but, though this is true in general, the idea should not be held to with too great tenacity in every case. That the eurypterids may well furnish an example of an exceptional case is shown by various lines of evidence which Chamberlin cites. First, of the dozen genera of eurypterids known in 1900 only two or three of the least well known are without associations with formations regarded as fresh water; secondly, he says: "The relics found in marine sediments may be attributed to transportation from the land just as is one in the case of terrestrial plants and land insects not infrequently found in marine beds; but transportation in the opposite direction cannot be assigned" (32). One may, however, take exception to this last statement, for many marine forms migrate up rivers in the spawning season, as for instance, the crabs which go up the Hudson as far as Albany; and there are many marine molluscs which become adapted to conditions in rivers and may even in time migrate to the land. Chamberlin says further that the eurypterids are found in abundance in fresh-water deposits with only a few trails of annelids suggesting marine conditions; they are assumed, therefore, to have been marine first and then fresh water, but in this case also why may we not consider that these forms were carried out to sea, rather than that they lived in marine water?

In direct opposition to this line of argument, Zittel in his *Grundzüge der Palæontologie* (**327**, 527) offers the following: "The Eurypterida are found associated with Graptolites, Cephalopods, and Trilobites in the Ordovician of Bohemia* and North America; with marine Crustacea (Phyllocarids and Ostracods) in the Silurian; with Ostracoderms and Arthrodires in the Devonian; and with land plants, scorpions, insects, fishes, and fresh-water amphibians in the productive Coal Measures. It is apparent, therefore, that from being originally marine forms, they became gradually adapted to brackish, and possibly even to fresh water conditions."

Clifton J. Sarle in 1898 discovered a new eurypterid fauna at the base of the Salina, Middle Siluric, of western New York (**240**). This formation had hitherto been considered particularly barren of fossils, but Sarle found in two layers of the Pittsford black shales such an abundance of eurypterids that some layers were "literally packed" with their remains. The two shale beds are intercalated between dolomite layers which, Sarle remarks, represented more open water and were apparently unfavorable to the eurypterids. The occupation of the black shales by these animals "was apparently of comparatively short duration, merely an incursion, as it were, since the black shale all told does not exceed 2 feet in thickness. The fact that the eurypterids are often dismembered and their parts distributed over considerable areas, and that a dozen or more are frequently found side by side . . . . suggests that they may have been drifted up by a current. On the other hand, the fine preservation of much of the material, extending even to the delicate appendages, shows that the currents were very weak, thus practically leaving the animals in the position of death or molting" (**240**, 1086).

A. W. Grabau in his *Physical and Faunal Evolution of North America during Ordovicic, Siluric, and Early Devonic Time* (1909) makes the facts of distribution an argument in favor of a fluviatile habitat, thus calling attention to one of the most important aspects

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* No eurypterids have been found in the Ordovicic of Bohemia. This statement was not corrected in the 1910 edition of the *Grundzüge der Paläontologie*, p. 568, but has been corrected in the 1913 edition of the *Text-Book of Palæontology*, p. 779.

of the problem. "The Eurypterid fauna also occurs in the mud layers in the Shawangunk conglomerate, which hardly admits of any other interpretation than deposition by torrential rivers. This would make the urypterid fauna a fresh-water fauna, an interpretation which best corresponds with the distribution of these fossils geologically as well as geographically. The Salina series is best understood as a desert deposit. The absence of organic remains (with the exceptions noted), known to be abundant in all modern salt deposits of sea-margin origin; the thickness of the salt beds; their limitation to circumscribed basins, the red color of the lower shales, their mud-cracks, all point to a continental origin" (**84**, 245). Clarke in reference to this fauna says: "Our present knowledge of the habits of the merostome crustaceans derived both from the living and fossil forms, indicates the shallow water or barachois origin of all sediments in which these remains abound" (**36**, 302). He does not, however, accept Grabau's interpretation of a torrential origin for the Shawangunk deposits, but thinks rather that they were formed in an Appalachian Gulf cut off from the ocean on the east by the Shawangunk Mountains, the material being swept down from the land and forming a delta deposit, the terrestrial waters preventing a highly saline condition in the gulf. The eurypterids, according to this view, were marine forms caught in a gulf of not too great salinity.

In the second volume of Chamberlin and Salisbury's *Geology* published in 1907, the eurypterid problem 's again taken up as follows: "These giants among their kind seem clearly to have been aquatic forms, but whether they were primarily marine or fresh-water habitants is not so obvious. They are wholly extinct, and their habitat can only be inferred from their associations. Some crustacean fragments that seem to belong to the same sub-class as the eurypterids (Merostomata) have been found by Walcott in Pre-Cambrian beds, but their associates are too few to throw much light on this question, though they favor a marine habitat." (Walcott considers that they favor non-marine conditions.) "A very few eurypterids appear in the Ordovician, where they are associated with marine invertebrates. In the Waterlime beds they are associated with ceratiocarids and ostracods which are usually marine, and very rarely, with certain brachiopods which are marine. In the transition beds of England, Sweden, and Russia, the eurypterids are associated more freely with marine forms, but they are also associated with the seeds of land plants and with fish which in the succeeding stage, seem to have occupied land waters chiefly. In the Devonian and Carboniferous periods, in which the eurypterids reached their climax and passed into their decline, and where they seem to have been in their more natural relations, they are associated with land plants, scorpions, insects, fishes, and fresh-water amphibians, which seem to imply a fresh-water habitat. In the light of these facts, the more common inference has been that they were originally marine forms, and became adapted later to brackish and fresh-water conditions. The alternative inference is that they were originally denizens of the land waters, and that their remains were occasionally and sometimes quite freely carried out to sea by stream waters, and were thus fossilized with marine forms. Their occasional presence in the earlier periods is thus explained, while their seemingly sudden appearance in abundance and in gigantic forms in the closing Silurian, and their prominence in the land-water deposits of the Devonian and Carboniferous finds ready explanation in the fact that these are the first well-preserved fossil-bearing deposits of land waters. In these deposits the eurypterids often appear without any marine associates, while occasionally there are some marine or at least brackish water forms associated with them, implying either that they lived in brackish or salt water at times, or that their remains were carried out into such waters by the land streams or estuarine currents" (33, 412).

It is to be noted that European authors have said very little about the habitat of the eurypterids, though there are a few brief references. Geikie is the one exception, for he has a good deal to say about the merostomes and the faunas which occur with them. I shall at this point merely quote a few of these passages, written in the discussion of the Upper Siluric occurrences and of those in the Old Red sandstone. "Vegetable remains, some of which seem to be fucoids, but most of which are probably terrestrial and lycopodiaceous, abound in the Downton sandstone and passage-beds into the Old Red Sandstone. The eurypterid genera continue to occur, together with phyllocarids (*Ceratiocaris*) and vast numbers of the ostracod *Beyrichia* (*B. Kloedeni*). Prevalent shells are *Lingula cornea* and *Platyschisma helicites*. The Ludlow fishes are also met with" (74, 961). In the discussion of the deposition of the Old Red Sandstone in basins Geikie says: "An interesting confirmation of the view that these basins were isolated is supplied by the occurrence of what is believed to be the oldest lacustrine or fluviatile mollusk yet known, *Amnigenia* (*Anodonta*, *Archanodon*) *jukesii*. This shell has been found in the Upper Old Red Sandstone of Ireland and England associated with land-plants (*Archaeopteris*, *Sphenopteris*, *Bothrodendron*, *Ulodendron*, *Stigmaria*, *Calamites*), fishes (*Coccosteus*) and arthropods (*Eurypterus*)" (**74**, 1003, 1004).

Steinmann in his *Einführung in die Palæontologie* merely states that: "These remarkable Crustacea reaching a length of 2 meters appear in the Cambrian and Silurian in association with marine animals, in the Devonian they live with the armor-plated fishes in the Old Red, in the Carboniferous and Permic they are found in fresh-water" (**266**, 373).[1] Haug speaks of the salt and gypsum deposits of New York as lagoon formations, and includes here also the eurypterid beds at the end of the Siluric, thus reaching the same conclusion that many American authors have come to (**112**, 626).[2]

Walther in the chapter entitled *Das Aufblühen der Tierstämme in Silur* in the *Geschichte der Erde und des Lebens* has accepted the statement of several American geologists that the eurypterids were marine organisms saying that they lived in sea-water of normal salinity "as the section in North America proves with certainty" (**294**, 251). The reference cited for this proof is Sarle's paper on the fauna from the Salina of Western New York. The significance of this occurrence will be discussed below, but we may say at this point that this instance seems hardly to furnish proof positive of a marine habitat. He also calls attention to the restriction of the eurypterids to the black shales, and of the absence of marine forms in association with the merostomes.[3] He notes that in synchronous formations the eurypterids are found only in isolated localities. "Thus is the upper Silurian of Pennsylvania devoid of Eurypterus for a thickness of 500 meters" (**294**, 251). Walther's explanation of the isolated occurrences seems hardly to accord with the facts. He assumes that the regions devoid of eurypterid remains were great salty lakes cut off from the sea in which the eurypterids are supposed to have lived.[4]

Ernst Stromer in the *Lehrbuch der Palaeozoologie* has added noth-

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[1] "Diese merkwürdigen, bis 2m. langen Krebse erscheinen in Kambrium und Silur in Begleitung von Meerestieren, im Devon leben sie mit Panzerfischen in Oldred, im Karbon und Perm finden sie sich in Süszwasserablagerungen."

[2] "Les formations lagunaires jouent un rôle peu important et l'on ne peut guère citer comment elles que des grès et des argiles rouges, qui, dans l'état de New-York et sur les bords de la Léna, renferment du gypse et du sel gemme, puis les *couches à Gigantostraces* et à Poissons, par lesquelles se termine souent le Silurien."

[3] "Hier folgt auf den fossilreichen Riffkalk ein dunkler Kalkmergel, der kein einziges der vorher hier so üppig gedeihenden Meerestiere enthält. Nur ein paar Schalen von Orthoceras wurden durch Stürme in die Bucht hineingetrieben, und einige genügsame Zweischaler lebten darin. Dann folgt ein schwarzer Mergel, reich an Eurypterus, und sobald dieses Gestein verschwindet, fehlen auch die Schildtiere und treten erst wieder auf sobald der schwarze Mergel nochmals erscheint." (**294**, 251.)

[4] Grosse Muschelkrebse (Leperditia) mögen hier einen salzigen Binnensee ohne Verbindung mit dem Meere belebt haben, so dasz die Schildtiere nicht hineinzudringen vermochten (**294** ,251).

ing new to the opinions already expressed by so many authors. "It is an oft observed phenomenon that groups originally flourishing in the sea are confined during their decline in fresh-water. Here this applies only to the Gigantostraca [Merostomata], while the Xiphosura which appear formerly to have lived mainly in inland seas, are, today, however, marine only" (**269**, 308).

During the year 1911 several papers on the Eurypterida appeared in America. Clarke still held to his former opinion that "the few eurypterids we know were doubtless marine, and the creatures gradually acquired the brackish-water habit at their climax, which seems to have eventually changed to a fresh-water life" (**37**, 280). Stuart Weller in his discussion of the nature of seas in which dolomites are formed, brings out several good points. "In such magnesian beds as are present in the Cayugan period of the Silurian [i.e., Middle and Upper Siluric] we find a most peculiar fauna, constituted almost wholly of the strange Eurypteroid Arthropods whose fossil remains are almost never found in association with typical marine faunas, but which are present in situations, such, for instance as the plant-bearing beds of the Pennsylvanian, which indicate that they must have lived in non-marine waters. The stratigraphic association of these Cayugan, Eurypterus-bearing beds with beds of salt and gypsum at once suggests that the waters of the period were highly saline and perhaps shallow; but, so far as I am aware, there is no inherent characteristic of the fossil Eurypterus which can in any way suggest that it may not have been a truly marine organism, and our conclusion that it was not such an organism is drawn from the physical surroundings of the fossil itself, rather than that the physical conditions are what we believe them to be on account of some peculiarity of the fossil" (**296**, 228). This point is well made, and is worth while remembering, namely, that there is nothing in the physical characters of the eurypterids to indicate that they lived in non-marine any more than in marine waters, but from their surroundings the former habitat is suggested. Moreover, the interpretation of the physical conditions of that time has not been based upon speculations about the characters of the eurypterids; it was definite knowledge about the physical conditions that makes it possible to say what must have been the character of the habitat of the eurypterids.

At the Kingston Meeting of Eastern Geologists in the spring of 1910 there was a warm discussion about the eurypterid habitat, Ruedemann, Schuchert, Hartnagel and others arguing in favor of the marine, Grabau in favor of the non-marine. The Waterlime formation was particularly under discussion, but though many arguments were brought up on both sides, neither was able to convince the other.

In the June number of the *Bulletin of the Geological Society of America* (1911) Clarke writing, on the "Relation of the Palaeozoic Arthropods to the Strand-Line," speaks of the size of the eyes of eurypterids and crustaceans as indications of the depth of water in which the forms lived. It was formerly supposed that crustaceans with large eyes had acquired them by adaptation to great depth of water. Clarke cites the case of a trilobite with enormous compound eyes living among many Cambric forms wholly devoid of lenses, and other examples of a contradictory character, so that the size of the eye cannot be taken as proof of either deep or shallow water, but rather implies that the complex, highly-specialized eyes of certain forms enables these individuals better to adapt themselves to either deep or shallow water conditions. Clarke reiterates the opinion that "the few early eurypterids we know were doubtless marine, and the creatures gradually acquired the brackish-water habit of their climax, which seems to have eventually changed to a fresh-water life" (37, 280).

In 1912 the most recent contribution to the study of North American eurypterids was made in Clarke and Ruedemann's ***Monograph on the Eurypterida of New York*** (39). While the work has to do mainly with the description of species and the study of larval stages and of the anatomy, leading to fuller knowledge of the ontogeny and phylogeny of the eurypterids as well as their taxonomic relations, still the authors have given some attention to the question of the bionomy (39, 96–113), coming to the following conclusions:

"Summarizing these data we conclude that the eurypterids lived in the sea from Cambric to Siluric time. They had then become less sensitive to changes, positive and negative, in the salinity of the water. In fact they seem to have thrived best under conditions of life that excluded most other marine groups of animals, that is, in the marginal, more or less inclosed marine lagoons, accompanied by estuaries receiving delta-forming terrestrial drainage, with prevailing arid or sub-arid climate, the waters being in some places more than normally briny, in others having less than normal salinity. In other words they were ***euryhaline*** or able to live in both salt and brackish water.

"Their adaptation to such conditions is paralleled today by such crustaceans as Apus and Artemia which not only thrive under rapid diminution of normal salinity but, by means of strongly protected eggs, even survive salt pan conditions which end in complete desiccation, as shown by their well known occurrence in desert lakes. The usual associates of the Siluric eurypterids are peculiar crustaceans whose nature emphasizes the reference above made. They are phyllocarids and ostracods and members of the strange family Hemiaspidae (Neolimulus, Bunodes, Hemiaspis, Pseudoniscus). This congeries of peculiar crustaceans seems to constitute a fauna especially adapted to, and therefore highly characteristic of, lagoon and estuary conditions.

"Thus while the earlier eurypterids were marine and their climacteric fauna euryhaline; their later habit throughout the Devonic and Carbonic led them finally into the fresh water.

"The succession of habitats is hence, according to our evidence, the reverse of that suggested by Chamberlin's hypothesis noted at the beginning of this discussion" (39, 112, 113).

In 1913 appeared the first extensive discussion of the habitat of the eurypterids in a paper entitled "Early Palaeozoic Delta Deposits of North America" by Professor Grabau, in which he brings forward arguments for the fluviatile habitat of these merostomes in the Ordovicic and Siluric of North America, and he includes a summary of the distribution and occurrence of the eurypterids by myself, reviewing the evidence and coming to the conclusion that the eurypterids were river-living at least during the two periods mentioned. The significance of the occurrences in the Pittsford, Shawangunk, and Bertie are discussed especially.

At the end of the same year Grabau's *Principles of Stratigraphy* was published. In Chapter XXVIII on the "Bionomic Characteristics of Plants and Animals" and elsewhere in the book the eurypterids are spoken of as fluviatile organisms as indicated by their distribution, faunal associates and mode of occurrence. A single statement taken from this book will show the position which Grabau holds. ". . . . The early remains of fish as of eurypterids are not found in normal marine deposits, but in those which are at least open to the suspicion that they are formed by rivers or at least at the mouths of rivers, while the best preserved remains, and the most abundantly represented in the Palaeozoic, are found in river flood-plain deposits and in deltas" (**87**, 989). For further references on this subject in the *Principles* see pp. 377, 425, 945, 950, 1029, 1030.

This gives us, then, the last word on the subject up to the present time. Looking over the opinions which have been recorded in the preceding pages, one is struck with the diversity of conclusions arrived at by our greatest American geologists and by not a few of those of Europe. From 1818, when the first Eurypterus was found, though it was not described as such till 1825, down to the end of the century, it was practically a universal opinion that the eurypterids had been denizens of the sea. The species were described along with marine forms and were considered to have been marine also. The study of the taxonomic position of the Eurypterida, showing always more and more clearly their close relationship to the modern Kingcrab, Limulus, gave an added reason for assuming a marine habitat for the fossil forms. With the beginning of the present century came the awakening of geologists and paleontologists to the fact that perhaps these extinct Merostomata had not always lived in the sea, that they may even never have known marine conditions. The current opinion now is that the eurypterids lived in the sea from Pre-Cambric time through the Ordovicic. During the Siluric they gradually became adapted to brackish and fresh-water conditions, living in estuaries and lagoons in the Devonic and becoming entirely fresh-water habitants in the Mississippic, Carbonic and Permic. Grabau is the only staunch advocate of the non-marine habitat even from the earliest times, though Chamberlin, to be sure, has argued such a possibility, but his discussion is purely philosophical, and while interesting and full of suggestive ideas, it is, nevertheless, unsupported by the evidence necessary for definite proof of his theory.

In attacking this problem the most important thing to determine is whether the Eurypterida began their existence in the sea or in the land waters, and under what conditions they lived in pre-Devonic time, for after that, it is now generally conceded, they lived in terrestrial waters.

CHAPTER III

The Bionomy of the Eurypterid Faunas

INTRODUCTION

In the first chapter I confined myself to facts which consisted of observations made in the field or the laboratory by students of the rocks and of the faunas. Such facts covered data on the geological and geographical distribution of the eurypterids; in the second chapter I gave a resumé of the opinions which have been held by various writers in regard to the habitat of the eurypterids; the remainder of the paper will be devoted to the contemplation of the recorded facts whose interpretation will be undertaken in the light of principles recognized by the school of philosophical geologists. For this reason, I shall in nearly all cases use the deductive method of inquiry, establishing the general principles which may then be applied to the particular case in hand. It is evident, then, that before we can begin to adduce proofs favoring one mode of life or another for the eurypterids, we must have a good classification of habitats in which each type is clearly defined, and we must determine at the very outset whether there are any criteria which may be recognized in the rocks as absolutely diagnostic of the habitats of the past. In so far as deposits in the sea and on the land have received any consideration at all, distinctions have mainly been drawn on the physical characters of the sediments; but I believe that much more accurate and far reaching results are to be obtained from the study of the fossil faunas. These may be investigated from two points of view, either the *chorological*, or the *bionomic;* and besides these, there is yet a third line of approach, namely the *geological*, in which the physical characters and lithogenesis of the sediments, together with the correlation of synchronous deposits constitute the elements. These three lines of investigation deal with three, for the most part mutually independent groups of facts and I am convinced that any one will yield sufficient evidence to determine the nature of any past habitat. In this chapter I shall deal with the bionomic characteristics of modern habitats, and shall give the criteria for recognizing ancient ones, concluding with the special case of the bionomy of the eurypterids. The following chapter will be devoted to the geological evidence regarding the habitats, while I shall defer until the fifth chapter the chorological evidence which is more conveniently discussed with the geological occurrences in mind. In considering the habitats, we may confine ourselves to those which are aqueous, since certain anatomical features, such as the nature of the cephalothoracic appendages and the presence of branchiae on the abdominal appendages, establish beyond a doubt the fact that the eurypterids lived in the water and not on the land, as do their near relatives the scorpions.

Before attempting to draw conclusions about the conditions under which the Eurypterida must have lived, it is necessary to have in mind the physical and faunal characteristics of the various types of habitats. Since these characteristics have never, so far as the writer knows, been discussed at length, I shall here state some of the results of an extended study of aqueous habitats which in time will be published as a separate paper.[1]

CLASSIFICATION OF RECENT AQUEOUS HABITATS

The most natural and fundamental characteristic which can be recognized in classifying aquatic bionomic realms is salinity, on which basis it is readily seen that there are only two original habitats: (1) marine, (2) terrestrial fresh water. Animals living either in marine or in fresh waters may become adapted to water which is of a salinity intermediate between the other two and generally designated "brackish," or to a salinity greater than that of normal marine waters. Thus to the two original types of habitat may be added two others: (3) brackish water, and (4) super-saline water, which are never original habitats. By this is meant that, minor variations excepted, no aquatic forms ever originate in the brackish water of estuaries, lagoons, cut-off arms of the sea, or interior basins, or in the super-saline waters of lakes. (This will be demonstrated below, pp. 73, 76, 77.) That this should be the case is due to the evanescent character of such water bodies. It is, of course, conceivable that a body of this type, long persistent, might be peopled from the land or from another aqueous realm and that such a fauna might be specialized. To these principal types may be added certain minor ones, giving seven in all. In the following table are given the salinity types, and with them what seems to be the best salinity ranges. It is not of importance here to go into the reasons for the making of the limits, but it may be said that they are based on a large number of typical examples in each

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[1] Some parts of the following classifications were presented by the writer at the 1914 meeting of the Paleontological Society of America.

case. The various realms may be secondarily grouped according to occurrence, as marine and terrestrial. In this latter group, two further subdivisions may be made according to mobility: the *courant* and the *static* waters. I propose the term courant for all terrestrial waters which are constantly moving in a given direction, as do the rivers. The following table brings out these points, of which further discussion will not be given in this paper.

CLASSIFICATION OF AQUEOUS BIONOMIC REALMS ACCORDING TO SALINITY[2]

CLASSIFICATION		SELECTED EXAMPLES					
		Marine		Courant		Static	
Type of Salinity	Range in Permille	Examples	Per-mille	Examples	Per-mille	Examples	Per-mille
I. Fresh....	0.0–0.2			Amazon River at Obidos	0.037	Lake Erie	0.134
				Rhine at Cologne	0.178		
II. Subbrackish.....	0.2–1.0			Vistula near Culm	0.201	Laacher See	0.218
				Arkansas R.	0.794	Humboldt Lake	0.928
III. Brackish..	1.0–10.0	Baltic Sea	7.80	Salt River	1.234	Palic Lake	2.215
				Rio de los Papagayos	9.185	Lake Biljo	8.800
IV. Superbrackish.	10.0–20.0	Sea of Azov	10.60			Caspian Sea (in 1878)	12.940
		Black Sea	18.30				
V. Subsaline.	20.0–30.0	Arctic Ocean	25.50			Van Lake	22.601
		Hudson Bay	26.00				
VI. Saline....	30.0–40.0	Behring Sea	30.30			Albert Lake	39.772
		Atlantic Ocean	35.37				
		Red Sea	38.80				
VII. Supersaline..	40.0–289 plus					Tinetz Lake	289.000

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[2] The examples and salinities in this table are taken from the tables compiled from various sources by Professor Grabau, and given in the "Principles of Stratigraphy" (87). The classification is new.

RECENT AQUATIC FAUNAS

Having established what seem to be fairly accurate limits for the ranges in salinity in all of the waters on the surface of the earth, it becomes possible to study the faunas of these different realms, for the type of life in any given water body is more dependent upon the salinity than upon any other physical factor with the exception of extremes of temperature. The absolute necessity of studying recent faunas with particular attention to the types of organisms represented, and to the numbers of species and of individuals, has not been realized sufficiently in the past. The habitats of fossil faunas cannot be determined without a knowledge, an intimate knowledge, of the habitats of recent faunas. To be sure, there is little doubt about the kinds of organisms which make up a typical marine fauna; in many cases, too, there may be no difficulty in recognizing a fresh water (especially lake) fauna, but there is an undoubted haziness and lack of precision in all ideas connected with brackish waters and with the faunas thereof. When a given fossil fauna has shown certain peculiar characteristics, such, for instance, as a complete or almost complete absence of molluscan representatives or when the fauna has been confined to one or two classes of organisms, the custom has been and still is to say that the organisms lived in brackish water. It is, thus, necessary to determine the nature of recent faunas which are characteristic of the various bionomic realms, in order that we may, not without a fair degree of certainty, establish the criteria for determining the faunal nature of the habitats of the past.

MARINE. The marine fauna is always large and varied, comprising, typically, representatives from each taxonomic division among the invertebrates. Not only are there a large number of genera and species, but nearly all phyla are represented. For the mollusca alone the number of genera in a given region may run up into the hundreds and that of the species may be considerably over a thousand. The figures apply especially to the littoral zone, that belt along all coasts which is most favorable to life. There light penetrates to the bottom, the food supply is abundant, and varying substrata are available to suit the needs of different organisms. This zone, extending from high water approximately to the two hundred fathom line, is the one of greatest geologic interest because nearly all of the marine formations of the past were littoral; unequivocal abyssal deposits being very rare. Since practically all of the invertebrate organisms of this prolific littoral marine fauna are protected either by shells or by exoskeletons, each individual that dies leaves its record behind in some hard part which falls to the bottom when the animal dies, or else soon comes to rest there, where it is buried by sand or mud. Not only are the remains of the animals which lived in the littoral zone of the sea preserved in the deposits forming there, but many derelicts, dead or alive, are washed in from the land and the rivers and we have a phenomenon observable in no other bionomic realm, namely, the commingling in one life district of the remains of organisms from all the other districts. During storms, terrestrial animals are drowned in the torrential floods, trees and other vegetation are carried away in the undermining of the banks, and these, together with the remains of fluviatile organisms and even with the living forms which cannot resist the strength of the current, are all carried out to sea to be dropped and there entombed with the remains of marine organisms. In tropical and semi-arid regions such mingling of terrestrial and marine forms is the common, not the unusual, thing. Darwin has called attention to many such cases in his *Voyage of the Beagle*, where he describes the great drought which occurred between the years 1827 and 1832 in Buenos Ayres, South America, when the birds and animals died by the thousand, the vegetation became withered and parched, and the dry winds swept over the desolate waste of land desiccated and dusty. The large rivers shrivelled, the small ones disappeared altogether; and where a little water still remained in the broader courses, it became highly saline, bringing death to the animals who drank. Herds of cattle rushed into the river, crazed by thirst, and there perished from the salt water and because they were too weak to climb up the banks again. Following this drought which lasted five years, came the rainy season and torrential floods. "Hence it is almost certain," Darwin concludes, "that some thousands of the skeletons were buried by the deposits of the very next year" (**48**, 127). Not only in semi-arid climates where torrential floods are active, but even in pluvial climates are terrestrial and fluviatile organisms carried out to the littoral zone of the sea, where they are buried in the delta deposits together with marine shells and tests. Thus, terrestrial vertebrate remains have been found in the deltas of the Ganges and Zambesi, the bones of recent antelope, buffalo, lion, hippopotamus and other mammals having been recorded; in the Po delta arthropods occur with lignites. Such terrestrial relics are by no means confined to deltas or river flood plains, but are found along all coasts even where no rivers enter as well as at considerable distances from shore beyond the debouchures.

Walther makes mention of the occurrence of great rafts of trees off the mouth of the Congo, 450 km. from shore, some of these interlocking tree islands being 100 m. across. Agassiz likewise has noted in the Caribbean Sea, Helix, leaves, and other land organisms dredged from a depth of 1000 to 2000 fathoms, which is far beyond the littoral zone.

Thus we must conclude that in the marine waters, and especially in the littoral zone, there is not only an abundance of invertebrate organisms of nearly all phyla, but there are stragglers from other realms; insects and plants are blown out to sea, while terrestrial animals and vegetal remains, together with fluviatile organisms, are carried along by the rivers, all at length being entombed in the marine sediments with the hard parts of the organisms which lived and died in the sea. In such cases we should expect to find the fluviatile and terrestrial remains shattered and worn on account of being transported oftentimes for a considerable distance, and usually subject to partial destruction by the débris which the rivers carry. At any rate, it is apparent that it is customary, not anomalous, for the remains of terrestrial and marine organisms to occur together.

Fresh Water. The fresh-water faunas of rivers and lakes, on the other hand, present quite different features. While the number of individuals in a given river or lake may indeed be large, the number of genera and species is very small as compared with those in the neighboring marine waters. Furthermore, there are only a few large classes abundantly represented, such as the fish, molluscs, and protozoa, while all of the other classes, so well represented in marine waters, are in given rivers or lakes represented often by a single species only, or by none at all. Three comparative sets of figures for the molluscs will serve to illustrate how small the number of genera and species is in fresh water when compared with those in marine waters at approximately the same latitude.

Table showing number of Genera and Species of Mollusca in Various Bionomic Realms

LOCALITY	NIAGARA RIVER	SAGINAW BAY	WOODS HOLE, MASS.	MASS. COAST
	permille	*permille*	*permille*	*permille*
Salinity	0.134	0.105	30.0	35.0
Genera	15	23	133	175
Species	24	93	203	466

The complete known invertebrate fauna from Woods Hole numbers 1286 species, while in the open marine, somewhat more saline waters, the number is even larger (**270**, 85).

Brackish Water. In dealing with the brackish-water faunas many difficulties are encountered, because not very much work has been done in connection with the various brackish-water bodies and it is thus hard to obtain data. Two examples, the Baltic Sea, and the Severn Estuary will be discussed.

The Baltic Sea. One of the best known of brackish-water bodies is the Baltic, which, though it cannot be considered an estuary may yet serve admirably to demonstrate the changes in fauna which occur with changes of salinity. The Baltic lacks the tides which are characteristic in estuaries and therefore does not exhibit the pronounced changes from fresh to salt water twice a day. It is more static and shows in a large way the responses of the fauna to salinity. The North Sea has a normal marine salinity of 35.00 permille, which decreases steadily eastward in the Baltic. In the Skager Rak it is 34 permille, off Skagen, the northeasternmost point of Denmark, it is 30 permille, in the Kattegat 22, and in the Bay of Kiel 20 permille. Throughout the southern part of the Baltic, from the "Scheren," at the mouth of the Gulf of Finland, to Bornholm the salinity is from 7 to 8 permille at the surface and does not vary greatly in the depths. For instance, in the deepest part of the Baltic off the Island of Gotland the salinity is only 12 permille, and in the Bay of Danzig, which shows a yearly average of 7.22 permille at the surface, it is only 11.66 permille (average) at the depth of 105 meters. In the Bay of Riga the salinity is 6 permille, in the southern part of the Gulf of Bothnia it is 4 permille and gradually diminishes until the water is entirely fresh. Corresponding to these changes in salinity are certain very definite changes in the fauna (Fig. 1).

As the salinity decreases from that of normal sea water, 35.00 permille, the fauna changes from a typical marine one to one in which only certain groups are represented and finally to an entirely fresh-water fauna. Each phylum shows this change; Pouchet and de Guerne have reported that a truly marine crustacean fauna extends into the Baltic as far as Kalmar Sound, between Öland and Sweden, but that beyond this point the marine species are gradually replaced by certain euryhaline forms and finally by the fresh-water ones until at the head of the Gulf of Finland the planktonic crustacean fauna is made up entirely of fresh-water types. Thus *Evadne nordmanni* is very abundant in the western part of the Baltic, but is replaced eastward by *Bosmina longirostris;* another abundant euryhaline form is *Podon intermedius.* The replacing fresh water types are such as *Cyclops quadricornis*, *Daphnella brachyura*, *Daphnia quadrangula* and *Bosmina longirostris* (Pouchet and de Guerne, **223,** 919, 920). The mollusca show a similar change, the Littorina species, for instance, being replaced by Limnæa, while along the coast where the salinity is low both of these forms live together, and there also *Neritina fluviatilis*, a river form is found.

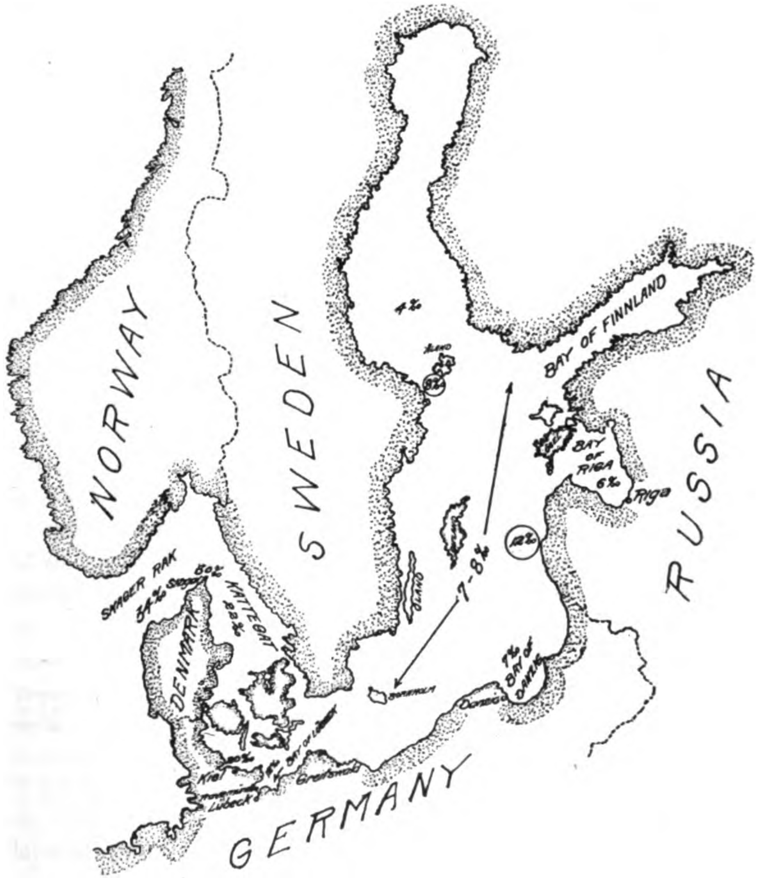

FIG. 1. SKETCH MAP OF BALTIC SHOWING PERMILLAGE VARIATIONS IN SALINITY

A second change which takes place in the Baltic fauna and which may be correlated with the variation in salinity, is that the stenohaline forms of the marine fauna disappear altogether, while the euryhaline ones become dwarfed. Thus, the common cockle shell, *Cardium edule*, in the North Sea, of normal marine salinity, is the size of a small apple, at Stockholm, where the salinity is below 10 permille, the shell in the deeper, more saline water is only as large as a walnut and is even smaller along shore where the water is fresher. At Königsberg, with the decreasing salinity, the size reaches that of a hazel nut, whereas at Reval, it is only the size of a pea. In like manner, *Mytilus edulis*, which is 8 to 9 cm. long at Kiel is only 3 to 4 cm. long at Gotland. The fish and worms also show dwarfing.

A third point to be noted is that the fauna decreases very rapidly in the number of species which occur. Karl Möbius in his report on the faunal survey in the Baltic Sea made by the Pommerania, states that:

"The total number of observed invertebrate animals amounts to about 200 species, not including the infusoria and crinoids.

"We have found scarcely one-fifth of these in the great eastern basin of the Baltic which begins between Rügen and the southern extremity of Sweden" (**182**, 277). The following table shows the distribution for the invertebrates. The numbers given for the Baltic as a whole should be compared with those given for Kiel. In this latter bay the conditions are not so different from those in the open

Comparative Number of Species of Invertebrates in the Baltic, etc.

PHYLA	WATERS AROUND GREAT BRITAIN	BALTIC AS A WHOLE	BAY OF KIEL	BAY OF TRAVEMUNDE
	35 permille	7.8 permille	20 permille	12 permille
Protozoa	69			
Porifera	42	7	3	3
Coelenterata	98	28	24	8
Echinodermata	48	6	5	2
Vermes	101	68	50	26
Bryozoa		11	8	5
Crustacea		50	36	19
Mollusca	682	68	64	40
Tunicata		5	4	4
Total	1040 (+)	243	194	107

sea as to have affected the fauna very markedly, but it will be noted that marine types must predominate in the fauna of the Baltic, as a whole, since for none of the phyla are the numbers much greater than they are at Kiel, where the fauna is wholly marine.

Perhaps the most significant fact brought out, is that the marine forms which are found in the Baltic, though they may be dwarfed or otherwise modified, are not different specifically from the marine forms found along the coasts of Great Britain, nor do the fresh-water forms differ from those found in the rivers emptying into the Baltic, or those in the neighboring fresh-water bodies. Thus it is established that in a brackish-water body of the nature of the Baltic the fauna is due to the mingling of modified marine and of modified fresh-water, that is, river forms. Only the more euryhaline marine species survive and these may in a given estuary give rise to a fauna which we may designate as a "brackish-water fauna." It will consist of forms derived in the manner just described, and these forms may become adapted to the peculiar temperature and salinity conditions prevailing in the given estuary. Thus, new mutations, varieties, and occasionally species may arise, but seldom a new genus and never a whole class of organisms. It is only the smaller taxonomic divisions which are affected. Furthermore, a "brackish-water fauna" in any estuary is always ephemeral, for the estuary is of short duration, geologically speaking.

The Severn Estuary. While the Baltic serves to show on a large scale what happens to a marine fauna which is gradually subjected to fresher and fresher water until it passes through brackish conditions to entirely fresh ones, there is another type of brackish water, the estuary, which is often said to have a fauna of its own. An estuary may be defined as the drowned lower portion of a river in which twice daily there is a change in the water from fresh to marine and back again as the tide comes in and goes out. On account of the tidal scour and thorough mixing of the marine and the inflowing river water, the brackish portion will not be very large. The Severn, on the west coast of England, is a very typical estuary, having the long, slowly broadening form toward the sea. There are a number of tributaries with their respective estuaries, so that on the whole the Severn may be considered characteristic. It is well known that muds are the dominant sediments, not only in the main tidal channel far out to sea, but also in all of the tributary channels. Professor W. J. Sollas has made a careful study of these muds in order to determine their distribution, origin and their included organic remains. In regard to the origin he says: "The rivers which discharge into the Severn estuary, draining, as they do, a catchment basin of 9193 square miles, are the chief sources of supply" (**264,** 611). A source of secondary, but by no means slight importance is the sea, which has worn off material from the cliffs and which has carried muds into the Severn. As Sollas has fully explained, though the details canno here be given, a small part of the silt which is brought down by the rivers may be deposited in the estuaries themselves, but the greater portion is carried seaward, "so that the final resting-place of the sediment of the Severn is situated some distance out to sea." A microscopic examination of the muds from a large number of localities on both sides of the Severn and along its tributaries revealed the following organic remains: "Coccoliths and rarely coccospheres, both of the ordinary cyatholith type so common in adjacent seas and in the Atlantic ooze; Foraminifera such as Miliola, Textularia, *Nonionina crassula*, *Polystomella umbilicata*, Rotalia sp., Spirillina sp. . . . spicules of Alcyonaria rarely; fragments of Echinoderm skeletons and minute spines: and triradiate spicules of Calcisponges, probably derived from *Sycandra ciliata* and *S. compressa.* The siliceous constituents are chiefly sponge-spicules, very rarely Radiolaria, and a variable quantity of Diatoms." The remarkable feature about these remains is that they are all marine, and yet they sometimes occur on the banks of the rivers at a great distance from truly marine waters. Moreover, the remains which are found are of organisms not living within many miles of the places where they occur, for Sollas has carried out a careful investigation of the fauna along the coast. He says: "Sponges do not grow anywhere so near Bristol on this side of the Channel as Portishead and Weston; Lynton, which is about 60 miles away, is the nearest possible locality; while Ilfracombe, about 15 miles further west, is well known as a rich collecting ground for both siliceous and calcareous sponges, and a host of other marine forms, including sea urchins and starfish, which might well furnish the echinoderm network and spines so frequent in the ooze. On the other side of the channel one would need to go to Bridgend before meeting with much in the way of shore life, and I doubt, after a hasty visit to that locality, whether much would be found there; a good deal farther west is Tenby, and no naturalist needs to be informed of the luxuriant growth of all kinds of marine animals, including sponges to be met with there" (**264,** 619). Sollas clearly shows that the remarkable distribution of marine remains far up the estuaries is due to the strong tidal current which brings the débis of organisms living along shore in the more open waters. This current rushes up the Severn at the rate of 6 to 12 miles an hour and it distributes the muds and microscopic organic remains as far north as Gloucester and to every estuary opening into the Severn. "On these shores, so remote from their source, some of these organic fragments find a permanent resting place, and thus far inland we discover along a river bank deposits, containing marine remains. But those which stay are few compared to those which are washed away again and carried out to sea, there to be deposited in marine mud-banks, probably not far from their original home" (264, 620). Just a few miles above the points at which the marine organic remains were found, the muds were examined and every sample showed abundant sponge-spicules, but these all proved to be of the fluviatile species, *Spongilla fluviatilis*, and none of the marine forms were found. This is the fauna of the recent muds, but a section through the older alluvial deposits which have a maximum thickness of 50 feet, shows that conditions have been much the same for a long time, and that there has been a constant alternation of conditions, first marine, then terrestrial, with the formation of peat beds. Wherever the estuarine sands and muds are washed over the peat beds a similar fauna, dominantly marine, though with fresh-water forms intermixed is found. The section is as follows in descending order:

Zone 1. Upper clay..
  a. More sandy zone, 5 to 7 feet
  b. More argillaceous zone, with disseminated vegetable matter 7 to 8 feet,
Upper peat, 1 to 2 feet, 6 inches.
Zone 2. Lower clay
Lower peat, 1 to 4 feet
Zone 3. Sands and mud
Gravel
Triassic sandstones

The deposits in the Severn estuary indicate a gradual subsidence of the land or advance of the sea. Both the upper and lower clay are blue and usually highly fossiliferous. In some sections a few feet will show an abundance of Foraminifera followed by several feet containing vegetal matter. In one section in which no peat was exposed the shaft sank through 39 feet of clay and then struck a marl bed one foot thick containing Limnæa, Planorbis, *Scrobicularia piperata*, *Cardium edule*, diatoms and Chara.

Yet another illustration of the nature of the faunas of estuaries may be found in the complete lists given in Verrill and Smith's invaluable report on the Invertebrate Animals of Vineyard Sound and Adjacent Waters (**280**). The fauna as there recorded from the sandy shores and bottoms of estuaries of the southern New England coast includes: Insects, Crustacea, Annelids, Gastropods, Pelecypods and Nemerteans all of which, with the exception of the last group, are represented by eight or more species (**280**, 170, 171); from the bottoms of sheltered estuaries, ponds, and harbors the following fauna is noted as characteristic:

Insects (4 species), Crustacea (30 sp.), Annelids (13 sp.),
Nemerteans (2 sp.), Nematodes (2 sp.), Gastropods (15 sp.),
Pelecypods (18 sp.) (Verrill and Smith **280**, 176–178.) The study of the brackish water bodies in the region just mentioned has shown that the animal life is very abundant and that the number of species found, while not so great as in the open sea, is still fairly large. Particularly is it to be noted that the species which do occur are abundantly represented and are remarkable for their hardiness and ability to live under widely varying conditions. A few of the species are restricted to the brackish water, but by far the largest number are able to live in pure sea water.

SUMMARY OF FAUNAL CRITERIA FOR DETERMINING THE TYPE OF AN AQUEOUS HABITAT

The chief faunal characteristics of recent aquatic bionomic realms may now be summarized.

1. The typical marine fauna is widespread, large, with an abundant representation in individuals, species, and genera from practically all of the phyla of the invertebrate animal kingdom. The various lithologic facies have their peculiar faunules, but each one of these contains types from all or nearly all of the phyla, while many cosmopolitan species, particularly among the pelagic plankton and nekton are entirely uninfluenced by the substratum and their remains consequently will be found with those of forms restricted to particular facies. Furthermore, terrestrial and fluviatile organisms will quite frequently be found in the marine fauna, having been transported

there alive or dead, and their hard parts will be preserved with those of the typical marine species.

2. The number of genera and species in fresh water is as a rule very much smaller than that in the neighboring sea, although the number of individuals may be nearly as large. Entire classes of organisms are wanting, while other classes are represented by only a few genera and species. Fresh water organisms are distributed by rivers and are found living in lakes and lagoons on the subaërial portions of deltas, in lakes, playas and more rarely epicontinental seas, all of which water bodies are geologically short lived.

3. Brackish waters may be considered under two types:

(a) The brackish waters or land-locked epicontinental seas such as the Baltic show a range in salinity from that of normal sea water to that of the rivers which empty into such water bodies. The fauna is made up of a modified marine and a modified fresh-water fauna, and always has its nearest relatives in the open sea, on the one hand, and in the rivers and connecting fresh-water lakes, on the other. Since the species contributed by the marine waters are so much more numerous than those contributed by the rivers, the greater number of the species in the brackish water will be related to marine forms.

(b) The brackish waters of estuaries are not stable enough to have a fauna which may be considered endemic. The marine fauna lives along shore and in the waters not too much disturbed by the tidal current, but the organic remains found in the estuaries are marine. Moreover, along the coasts affected by the deposition of the tidal muds, no organisms live and it is only many miles away from the estuary proper that the marine forms are found whose hard parts, carried by the tidal currents and in time comminuted, finally come to settle on the floors of the estuaries and on the river banks. These hard parts are carried up the estuaries as far as the tidal current is felt and it is only above this point that the fresh water forms are found. In the very small area between the purely fresh and the dominantly marine waters is the brackish-water area in which there may be a small mixed fauna.

APPLICATION TO THE PAST

Armed now with a considerable wealth of facts drawn from the present, we may turn to the past in an attempt to set forth any available criteria which may be used in determining the nature of a given habitat.

MARINE DEPOSITS AND FAUNAS. Sediments which accumulated in the open marine waters at all times, subsequent at least to the Pre-Cambric, have been found to contain a rich and varied fauna in which were represented all of the larger groups of the invertebrate animal kingdom which are recognized today. One need only mention the prolific faunas of the Cambric of St. John, New Brunswick, and of British Columbia, the Trenton of New York, the Niagaran of New York and elsewhere, the Hamilton of the eastern United States, the Muschelkalk and Upper Jura of Germany, the Upper Cretacic of the middle and north of Europe, and the Eocenic of France and England. Not only is the number of individual fossils great, represented by many species, but these species are scattered through many phyla, just as at the present time the organisms in the oceans are numerous and diversified, no one class reigning to the complete exclusion of others. This does not mean that we shall find the same distribution according to phyla in the past, but we do know that it will be diverse. The vertebrates, for instance, cannot be of importance in faunas until their evolution has had time to take place, and thus they are not found represented in the rocks in abundance before the Devonic. Thus the important phylum of Pisces find no, or only rare representation in the early Palæozoic rocks; but, on the other hand, there were the Crustacea throughout the Palæozoic, especially the trilobites, which became extinct at the end of that period. And so one might nicely appose the phyla, or more often orders or families, which were represented in the past, but are not now, and in this way we would see that the past, though different from, was similar to the present, and that Palæozoic seas, even the earliest ones, lacked not in life and in the diversity thereof.

The very nature of marine waters, their continuity and great extent, suggests migration and wide distribution through currents. Barriers there were, of course, both by land masses and ocean currents, streams of cold water, and so forth, but, nevertheless, we know that migration along the coasts of the continents took place as it does today and that many species or at least genera spread throughout all of the oceans, for if we did not believe in the forces of migration and dispersal we would not have laid down the laws of correlation which are universally recognized. In no way, then, can a typical marine fauna remain bottled up in one place, with none of its members escaping to adjacent waters; such a thing cannot happen today and it is not reasonable to suppose that it happened in any geological period in the past.

Fluviatile Deposits and Faunas. The importance of sediments containing river faunas has not heretofore been realized, nor have such sediments and their characteristics been dwelt upon by most geologists. Grabau has been the staunchest advocate of the fluviatile origin of many deposits both in this country and Europe, but has usually stood alone in his interpretations. In his paper on "Early Palæozoic Delta Deposits of North America" he has described in great detail a large number of delta deposits occurring in the Ordovicic and Siluric and has shown what are the characteristics physical and faunal of such deposits. Barrell has likewise made a number of contributions to the study of fossil delta deposits with especial emphasis on their physical characteristics, and on the climatic factors controlling sedimentation.

It is a matter of difficulty to determine much about rivers of older geological periods, because the river channels are seldom preserved, especially in the Palæozoic, and when found are visible, usually only in section and cannot be traced along the surface. Flood plain and delta deposits are almost the only records of their presence left by ancient rivers. It is not to be expected, however, that such deposits will be without fossils any more than similar deposits today are. Rivers carry large amounts of detritus varying in grain from fine muds, a fraction of a millimeter in diameter, to bowlders often several feet across, though these coarser elements are more likely to be carried by torrential or mountain streams than in the larger rivers. In a pluvial climate this load is brought into lakes or to the ocean and there deposited; in an arid climate it is spread out on interior plains or in basins in the form of alluvial fans or dry deltas. Since the lithological characteristics of deltas and flood plains are often of great assistance in the recognition of fossil deposits of this type, it may not be amiss to say a few words about them here.

The sediments spread out by a river in its lower reaches are of two types: (a) those which form directly at the mouth and are spread out in front of it into the sea, and (b) those which are spread out laterally either over the subaërial portion of the delta or along the flood-plain and over the neighboring lowlands throughout the lower portions of the river. These are the fine mud deposits of which we see such splendid examples in the case of the Nile and Mississippi deltas. The deposits in the Nile delta are thus described: "At low water these are visible in the steep banks which then rise 8 to 10 meters above water level. The hardened Nile mud forms a series of horizontal beds varying in thickness from a few inches to several feet, and looks more like an ancient stratified series than a modern deposit. The material of the Nile mud is a more or less uniformly fine-grained one, the size of the grains varying from $\frac{1}{18}$ to $\frac{1}{100}$ mm., rarely reaching to $\frac{1}{10}$ mm. in size" (Grabau, **87**, 614). The Mississippi delta is spread out in the remarkable bird-foot form and the whole of its lower part is covered with a network of distributaries which often empty into large fresh-water lakes. In these lakes and over all the interstream areas the fine muds are deposited. They contain shells of fresh-water molluscs and much driftwood, which is often united into floating rafts.

In the portions of the delta nearer the sea, fresh-water and marine organisms are both found, not intermingled, however, but in separate layers, depending upon whether beds were deposited in the sea or by the streams above the sea. Thus a bed with fresh-water shells and lignite is often intercalated between beds with marine remains, giving evidence of the shifting conditions of deposition in deltas where streams continually change their channels and where consequently the areas of terrestrial deposition are shifted, while the sea advances in the interfluve areas and a wedge of marine deposits is formed.

Here a few details in regard to the nature of the Indo-Gangetic delta will give a good idea of what types of sediments and organic remains are to be expected. Lyell states that "No substance so coarse as gravel occurs in any part of the delta of the Ganges and Bramapootra, nor nearer the sea than 400 miles (**154**, 280). A boring to a depth of 481 feet made near Calcutta showed below the surface soil, at the top of the first 120 feet of the boring, a stiff blue clay succeeded downwards by a sandy clay and this in turn by a peat bed. A nodular limestone, the kankar, of fresh-water origin, was encountered.[3] Below the first 120 feet there were found various beds "consisting of clay, marl, and friable sandstone with kankar here and there intermixed, [while] no organic remains of a decidedly marine origin were met with . . . . The only fossils obtained in a recognizable state were of a fluviatile or terrestrial character. Thus, at the depth of 350 feet the bony shell of a tortoise, or Trionyx, a freshwater genus, was found in sand, resembling the living species of Bengal . . . . At the depth of 380 feet, clay with fragments of lacustrine shells was incumbent on what appears clearly to have been another "dirt-bed," or stratum of decayed wood . . . .

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[3] For description of kankar, see Grabau's *Principles of Stratigraphy*, **87**, pp. 586, 719.

At a depth of about 400 feet below the surface, an abrupt change was observed in the character of the strata, which were composed in great part of sand, shingle, and boulders, the only fossils observed being the vertebrae of a crocodile, shell of a Trionyx, and fragments of wood very little altered, and similar to that buried in beds far above" (**154**, 281). This boring was very evidently through the subaërial portion of the delta, which was deposited at a time when the land stood higher and when, probably, hilly areas now removed by erosion or covered by deposits supplied coarser material near the seashore. The variability in the types of deposits is shown and it is seen that neither nodular limestones or conglomerates imply the presence of the sea for their formation. The sediments of the present delta are all fine-grained, the coarse deposits being found only at the foot of the mountains. Moreover, the fine sediments are carried far out to sea. "The sea, where the Ganges and Brahmapootra discharge their main stream at the flood season, only recovers its transparency at the distance of from 60 to 100 miles from the delta" (**154**, 279). In speaking of the Mississippi river Lyell says: "The prodigious quantity of wood annually drifted down by the Mississippi and its tributaries, is a subject of geological interest . . . . as illustrating the manner in which abundance of vegetable matter becomes, in the ordinary course of nature, imbedded in submarine and estuary deposits" (**154**, 268).

When the enormous transporting power of rivers is considered, when we think of the amount and variety of sediments together with terrestrial and fluviatile organic remains annually brought down to the sea by rivers there to be mixed with the marine sediments and the organisms living in the sea, we find it not so difficult to realize that the same phenomena happened in the past. The wonder would be if such intermingling had not taken place, and one must indeed be surprised to note how seldom it seems to have come to pass in the Palæozoic. Even admitting that land vegetation was mostly of a primitive, easily destructible, non-vascular nature in the Palæozoic, we still must marvel that so few fluviatile and terrestrial forms were carried out into marine deposits.

If the above characteristics are kept in mind it will not be difficult to formulate a certain number of criteria which may be used in recognizing a fossil delta or flood-plain deposit. That portion of the delta adjacent to the mouth of the river will be characterized by an alternation of marine and continental deposits, and these will be recognized in ancient deltas by a lithological and faunal interfingering. The silts brought down by the river will contain the remains of the river fauna, while the submarine deposits, be they sandstones, shales or limestones will contain a marine fauna. The two types of deposits as well as the two types of faunas, though they interfinger, will be of a distinct and recognizable character as a rule, and the nature of the faunas, in regard to numbers of individuals and species, will be recognized by the characteristics listed on page 77 above. The deposits on the subaërial portions of the delta and laterally in the flood-plain areas will consist of fine silts. Along the river banks the coarsest of the silts will be deposited and with them the heavier organic remains if there are any, such as the shells of molluscs. But with the finer silts periodically spread out at times of flood far to either side of the river, will be carried only the lightest materials, probably only plant remains and the exoskeletons of the various fluviatile crustaceous animals. Such organic remains may be carried out in great numbers, and if quickly buried will be excellently preserved in the fine muds. On the other hand, if they are carried a long distance, dropped and exposed to the air, and later perhaps picked up by some distributary and carried on again, the process being often repeated, they may be broken up, and when they finally come to rest and are buried, not a single complete organism will remain. Indeed, if in their final resting place they are exposed to the air for a long time and the mud on which they lie becomes sun-cracked, the fragments, drying up, may be blown for great distances, perhaps far inland or perhaps out to sea, coming to rest at last in regions far removed from those in which the organisms had lived and there amidst a strange fauna the remains may be entombed.[4] In the sediments such a history could be read, if in shales or waterlimes the only organic remains were those of light specific gravity. Of the invertebrates there would probably be some arthropods or insects; among the plants, leaves, algæ, reeds and grasses would be expected. Such a deposit would be difficult to correlate with a marine deposit, because it might contain none of the contemporaneous marine organisms. If, perchance, some of the river organisms or fragments of them had been blown or carried to sea, their remains could be entombed with the typical marine fauna and the age would thus be determinable. It is not unlikely, too, that stray molluscan shells might be blown from the shore

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[4] In this connection it is interesting to record that the eurypterids of Oesel have such a thin test, that specimens exposed by the breaking of the rock are not uncommonly blown away by the wind.

inland, as they are today, and might come to rest in the very muds in which the river organisms were buried. Likewise, in the low-lying portions of the flood plain near the sea, occasional high tides or inundations, through the wearing away of sand-bars, might allow the salt water to enter, carrying some marine shells into those regions. Then the fossil fauna would show a large number of forms belonging mainly to one phylum, the arthopods, and occasional single specimens of members from other phyla. If the opposite conditions prevailed, and the fragments of the arthropods or their exoskeletons were blown to sea, then the fossil fauna would reveal many marine organisms, complete and well preserved, from all or nearly all of the invertebrate phyla, and occasional fragments of another group of organisms which were not well preserved and whose occurrence in such surroundings seemed anomalous.

BRACKISH-WATER AND ESTUARINE DEPOSITS AND FAUNAS. It has been shown that at the present time there is no such thing as a brackish-water fauna made up of classes of organisms different from those found in neighboring marine and fresh waters. It might be extremely difficult to recognize from the sediments and fossils that any fauna had lived in brackish water, because unless the salinity had been reduced so much that it was nearly that of fresh water the fauna would not appear to be very different from a typical marine one, except that it would be dwarfed and would contain few species. An estuarine fauna would likewise be difficult to recognize from the fossils. These would, however, be likely to be fragmentary, even comminuted to microscopic size, and larger forms would be found only in the sands and coarser deposits along shore and not in the estuarine deposits proper. It has been seen that the conditions in an estuary are not favorable for supporting life. The tidal scour, the churning up of the water, keeping the sediments constantly in suspension, the sudden change in salinity twice every day, are environmental factors not at all conducive to attract marine animals which can find more stable and beneficial conditions along the coast on both sides of the estuary. Thus, we saw that in the Severn the organisms whose comminuted remains were found in the muds lived many miles away in the quieter waters north and south of the estuary. In the geologic column we shall probably rarely be able to recognize estuarine deposits from the faunas, but if at all it will be from the nature of the sediments, their lithological characters and sources.

THE EURYPTERID FAUNAS AND ASSOCIATED ORGANISMS

In the following lists the eurypterid faunas of the various occurrences is given, as well as the organisms other than eurypterids which are found associated with them. No account is taken here of single occurrences or of the presence of a few fragments in normal marine faunas.

ORDOVICIC

NORMANSKILL FAUNA.

Eurypterids.

- Dolichopterus breviceps
- Eusarcus linguatus
- Eurypterus chadwicki
- Pterygotus ? nasutus
- P. normanskillensis
- Stylonurus modestus

Associated organisms. Seaweeds and graptolites.

- Rhombodictyon
- Climacograptus bicornis
- C. bicornis var. peltifer
- Cryptograptus tricornis
- Dicellograptus gurleyi

SCHENECTADY FAUNA.

Eurypterids:

- Dolichopterus frankfortensis
- D. latifrons
- Eurypterus ruedemanni
- E. pristinus
- E. ? stellatus
- Eusarcus ? longiceps
- E. triangulatus
- Hughmilleria shawangunk
- Pterygotus ? nasutus
- P. prolificus
- Stylonurus limbatus

Associated organisms.

- In sandy shales, seaweed, Sphenothallus latifolium
- In black shales, graptolites and trilobites
- Climacograptus bicornis
- Triarthrus becki

SILURIC

EARLIEST LOWER SILURIC (Ee$_1$.) FAUNA OF BOHEMIA.

Eurypterids.

- Eurypterus acrocephalus
- Pterygotus barrandei

P. beraunensis
P. bohemicus
P. nobilis
P. cf. problematicus

Graptolites.

Monograptus turriculatus
Other species

UPPER LOWER SILURIC (Ee$_2$) FAUNA OF BOHEMIA.

Eurypterids. (All very fragmentary.)

Pterygotus barrandei
P. beraunensis
P. blahai
P. bohemicus
P. fissus
P. kopaninensis
P. nobilis
P. cf. problematicus
Slimonia cf. acuminata

Associated fauna.

The typical and abundant Upper Siluric of Bohemia.

WENLOCK FAUNA OF PENTLAND HILLS, SCOTLAND.

Eurypterids.

Bembicosoma pomphicus
Drepanopterus bembicoides
Drepanopterus lobatus
Drepanopterus pentlandicus
Eurypterus conicus
Eurypterus cyclophthalmus
Eurypterus minor
Eurypterus scoticus
Eurypterus, 3 sp. und.
Slimonia dubia
Stylonurus elegans
Stylonurus macrophthalmus
S. ornatus

Scorpion—Palaeophonus loudonensis
Ceratiocarid—Dictyocaris ramsayi (Taxonomic position doubtful)
Sponge—Amphispongia sp.

In beds above or below eurypterid layers, the following fauna has been found:

Graptolites

Dictyonema venustum
D. (Chondrites) verisimile
Cyrtograptus murchisoni ?
Monograptus priodon
M. vomerinus

- *Coral*—Favosites sp.
- *Asteroidea*—Palasterina sp.
- *Crinoids*—fragments
- *Brachiopods*—
  - Lingula lewisi
  - L. symondsi
  - Strophomena walmstedti
- *Gastropods*—Euomphalus rugosus
- *Cephalopods.*
  - Orthoceras angulatum
  - Gomphoceras ellipticum
- *Conulariida*—Tentaculites tenius
  - Conularia monile
  - C. sowerbyi
  - C. sp.
- *Problematic*—Nidulites favus.

Shawangunk Fauna of Eastern North America.

- *Eurypterids.*
  - Dolichopterus otisius
  - D. stylonuroides
  - Eurypterus maria
  - Eusarcus cicerops
  - Hughmilleria shawangunk
  - Pterygotus globiceps
  - Stylonurus cestrotus
  - S. myops
- *No associated organisms*

Pittsford Fauna of New York.

- *Eurypterids.*
  - Eurypterus pittsfordensis
  - Hughmilleria socialis
  - H. socialis var robusta
  - Pterygotus monroensis
  - Stylonurus (Ctenopterus) multispinosus
- *Crustacea.*
  - Ceratiocaris praecedens
  - Emmelezoe decora
  - Pseudoniscus roosevelti

Fossils in dolomite partings but not in the black shales and not associated with the eurypterids.

	Genera
Graptolitida	1
Annelida (denticles)	3
Brachiopoda (Lingula)	1
Pelecypoda (Pterinea cf. emacerata)	1
Cephalopoda (Orthoceras and Gomphoceras)	2
Ostracoda (Leperditia scalaris)	1

BERTIE FAUNA.

a. Bertie fauna of Erie district.

Eurypterids.

Dolichopterus macrochirus
D. siluriceps
Eurypterus lacustris
E. lacustris var. pachychirus
E. pustulosus
Eusarcus scorpionis
Pterygotus buffaloensis
P. cobbi
P. grandis

Associated forms.

Cephalopods—Orthoceras undulatum
Trochoceras gebhardi
Brachipod—Lingula sp.
Ostracod—Leperditia alta
Pelecypod—Goniophora sp.
Pulmonate Gastropods—Hercynella buffaloensis
H. patelliformis
Graptolites—"Buthrotrepis lesquereuxi" (formerly considered a seaweed, now identified by Ruedemann as graptolites)
Ceratiocarid—Ceratiocaris acuminata
Plant—Chondrites graminiformis (may be a graptolite)

b. Bertie fauna of Herkimer district.

Eurypterids.

Dolichopterus macrochirus
D. testudineus
Eurypterus remipes
Pterygotus macrophthalmus
P. cobbi

Associated forms.—Scorpion

Proscorpius osborni

KOKOMO FAUNA.

Eurypterids.

Eurypterus (Onychopterus) kokomoensis
E. ranilarva
Eusarcus newlini
Stylonurus (Drepanopterus) longicaudatus

Associated forms.

Ceratiocarids

UPPER SILURIC FAUNA OF OESEL.

Eurypterids.

Eurypterus fischeri
E. fischeri var. rectangularis

E. laticeps
Pterygotus osiliensis
Eusarcus simonsoni
Ceratiocarid—Ceratiocaris
Fishes (Celphalaspid)
Thyestes verrucosus
Tremataspis schrenkii
Crustacea (Hemiaspidæ)
Bunodes lunula
B. rugosa
B. schrenkii
Synxiophosuran: Pseudoniscus aculeatus
Ostracod: Leperditia sp.
Cephalopod: Orthoceras tenue

TEMESIDE FAUNA OF ENGLAND.

While this fauna is sparingly represented in a number of beds in this group, all of the species occur together at only one horizon, namely, in the Olive shales below the Temeside Bone-Bed. Unless otherwise indicated, forms are abundant.

Eurypterids.
Eurypterus acuminatus (r)
E. pygmaeus
E. spp.
Pterygotus banksii
P. gigas
P. ludensis
P. problematicus
Parka decipiens (eggs)
Crustacea.
Beyrichia kloedeni
Leperditia phaseolus var. gracilenta (r)
L. small species
Physocaris vesica
Plantae.
Pachytheca sphaerica (cc)
Pisces.
Auchenaspis salteri (r)
Cephalaspis murchisoni (r)
Ctenacanthus (r)
Onchus murchisoni
O. teniustriatus
Brachiopods.
Lingula cornea (cc)

LUDLOW FAUNA OF SCOTLAND.

Localities in Lesmahagow inlier.
(1) Along the banks of Logan water in *Ceratiocaris beds*
Eurypterid: Slimonia acuminata

- *Ceratiocarids.*
    - Ceratiocaris laxa
    - Ceratiocaris longa
    - Ceratiocaris papilio
    - Ceratiocaris stygius
    - Ceratiocaris cf. murchisoni
- *Worm tracks.*

(2) In same bed ½ mile distant:

- *Eurypterids:*
    - Pterygotus bilobus
    - Slimonia acuminata
- *Ceratiocarids:*
    - Ceratiocaris sp.
    - Dictyocaris ramsayi
- *Coelolepid fish:* Thelodus scoticus
- *Myriopods ?* impressions of

(3) From Long Burn, tributary of Logan Water in same bed

- *Eurypterid:* Pterygotus bilobus
- *Ceratiocarid:*
    - Dictyocaris ramsayi (Taxonomic position doubtful)
    - Ceratiocaris sp.
- *Ostracods:* Beyrichia kloedeni
    - Beyrichia kloedeni var. torosa
- *Pelecypods:* Modiolopsis nilssoni
    - Orthonota sp.
- *Brachiopod:* Lingula minima
- *Gastropod:* Platyschisma (Trochus) helicites
- *Worm tubes:* Spirorbis sp.

(4) One half south of Logan House in "fish-band"

- *Eurypterid:* Slimonia acuminata
- *Ceratiocarids:* Ceratiocaris longa
    - C. murchisoni
    - C. papilio
    - C. stygius
    - Physocaris sp.
- *Coelolepid fish:* Thelodus scoticus
    - T. planus.
    - Fish fragment undet
- *Myriopods:* Archidesmus loganensis

(5) At Logan Water in *Pterygotus* beds overlying *Ceratiocaris beds.*

- *Eurypterids:* Eurypterus lanceolatus
    - E. obesus
    - E. scorpioides
    - Pterygotus bilobus
    - P. bilobus var. acidens
    - P. bilobus var. inornatus
    - P. raniceps
    - Slimonia acuminata
    - Stylonurus logani

Ceratiocarid: Ceratiocaris papilio
Synxiphosuran: Neolimulus falcata

Note: In same locality Pterygotus and Slimonia are found in abundance associated with *Beyrichia kloedeni* and *Ceratiocaris*.

LANARKIAN FAUNA OF SCOTLAND.

Localities in Hagshaw Hills anticline
Glauconome layer in bed 9
Eurypterid: Eurypterus dolichoschelus
Coelolepid fishes: Lasanius problematicus
Ateleaspis tessellata
Bryozoan: Glauconome disticha
Sponge.
Worm tube: Spirorbis sp.

DEVONIC

OLD RED SANDSTONE FAUNA OF SCOTLAND.

a. Pterygotus beds of Carmylie.
Eurypterids:
Pterygotus anglicus (cc)
Parka decipiens (eggs)

b. Acanthodian beds of Turin Hill (Arbroath flags).
Eurypterids:
Eurypterus brewsteri
E. pygmaeus
Pterygotus anglicus
P. minor
Stylonurus scoticus
S. ensiformis
S. powriei
Fishes:
Mesacanthus mitchelli
Ischnacanthus gracilis
Climatius scutiger
C. uncinatus
C. reticulatus
C. macnicoli
C. grandis
C. gracilis
Parexus recurvus
P. falcatus
Euthacanthus mitchelli
E. elegans
E. curtus
Cephalaspis asper
C. lyelli
Thelodus pagei

Plants:
    Pachytheca, etc.

c. Old red sandstone of Lorne
    Eurypterids:
        Pterygotus cf. anglicus
    Fishes:
        Cephalaspis lornensis
        Mesacanthus
        Thelodus (?)
    Ostracods:
        Aparchites
        Isochilina
        Beyrichia
    Chilognathous myriopods:
        Kampecaris
        Archidesmus
    Plants:
        cf. Psilophyton

d. Upper old red sandstone fauna of Ireland
    Eurypterids:
        Eurypterus hibernicus
        E. scouleri?
    Fluviatile pelecypod:
        Amnigenia (Anodonta) jukesii
    Fishes:
        Coccosteus
    Plants:
        Archaeopteris
        Bothrodendron
        Calamites
        Sphenopteris
        Stigmaria
        Ulodendron

In the preceding lists only those faunas have been given which are abundantly represented in species and individuals, and which may, therefore, be considered characteristic. Of all the faunas cited, that from the waterlimes of Oesel, while not containing the largest number of species, is yet the one which is preëminently representative. The eurypterids undoubtedly lived and died in the muds now forming the waterlimes, the remains which are found there having suffered practically no transportation, as we may judge from the perfection of preservation and the entirety of individuals. The specimens of *Eurypterus fischeri* occur in greater numbers and in a more perfect state than do those of any other known species, and the exoskeletons are not only not compressed, but they even show the original chitin and specimens can be removed from the rock almost entire; the surface sculpture and internal structure are as clearly visible as in a Limulus buried in the sand but yesterday. We have here, if anywhere, a representation of the normal habitat of the Eurypterida, and likewise the normal faunal associates. The analysis of this fauna shows that besides the eurypterids there are a number of crustacea which are commonly found with the merostomes, but never in a typical marine fauna, two species of fish of the type characteristic of the Old Red Sandstone, an ostracod and *Orthoceras tenue*. The presence of this single cephalopod has been considered by some authors to be so important that they would brand the whole fauna as a modified marine one, because of it; and yet the startling and commonly neglected fact is that this thin shelled Orthoceras is most evidently out of place, for while the eurypterids are so marvellously preserved, this one rare cephalopod is worn, macerated, and flattened into a tenuous, carbonaceous film, and thus there is no doubt that it was transported from its normal habitat and came probably as a dead shell into the region where the eurypterids were living. Its presence is truly of great importance as being the very exception which proves the rule that the eurypterids were not normally marine.

A glance at the components of the fourteen faunas listed shows that there is not a single case in which several species of eurypterids are found in a fair state of preservation in such numbers as to be considered a recognizable faunule—there is not a case, to repeat, in which the faunule, including all of the organisms represented, can be considered either marine or modified marine, that is, brackish or estuarine. The most constant associates of the eurypterids from the earliest Siluric on are certain peculiar crustaceans, Ceratiocaris, and the like, which are never found with the molluscs, brachiopods, and trilobites which are characteristic of marine faunas. The oldest scorpion known comes from beds carrying eurypterids, similarly the earliest fluviatile pelecypod and the first myriopods were also found in eurypterid formations. In North America, England, Scotland, and on the continent the forerunners of the Old Red Sandstone fishes, now almost universally recognized to be fluviatile, are found in the Siluric with the eurypterids, crustacea and spores of land plants, but not in the beds carrying typical marine fossils.

In the Bertie waterlime, which is second only to the waterlime of Oesel in importance, a large eurypterid fauna is found with abundant Ceratiocaris, two species of pulmonate gastropods, a problematic plant, and a few very poorly-preserved, marine fossils, which last, by their very scarcity and by the evidences which they show of having been transported, argue more strongly for than against the extra-marine habitat of the well-preserved eurypterids and Ceratiocaris.

The application of the criteria for the recognition of the types of fossil faunas and habitats shows beyond any doubt that the eurypterids, so far as we now know, never lived in the sea or in any partially or wholly detached portion thereof; the only possible type of fauna to which the eurypterids could have belonged was that which dwelt in rivers, and this is nowhere more clearly shown than in the Siluric, which marked the acme in development and universality of distribution for the Eurypterida.

CHAPTER IV

The Lithogenesis of the Eurypterid-bearing Beds

The formations which in America contain eurypterids in abundance are:

1. The Belt Terrane.
2. The Normanskill and Schenectady beds.
3. The Shawangunk conglomerate.
4. The Pittsford shale.
5. The Bertie waterlime.
6. The Kokomo waterlimes.

Those most prolific in Europe are:

7. The Tarannon and Wenlock beds of southern Scotland.
8. The waterlime beds of Oesel.
9. The Siluric of the Austro-Russian border lands.
10. The Ludlow of England and Ludlow and Lanarkian of Scotland.
11. The Old Red Sandstone.

It is evident that the formations carrying only fragments or single individuals need not be considered if we can prove a uniform habitat from the formations carrying these merostomes in abundance. Nevertheless a brief summary of these is also given at the end of the chapter.

1. THE BELT TERRANE

The Belt Terrane fauna is a large one made up of fragments which Clarke and Ruedemann have failed to identify as of merostome origin, though Walcott insists that they belong to this group. Clarke and Ruedemann hold, however, that the specimens from the Altyn limestone of Alberta are undoubtedly merostomes, but they question the correlation of the Altyn and Belt Terrane, and the consequent reference of the remains from the two formations to *Beltina danai*. (This has been discussed on pp. 11-13.) The Belt Terrane material, nevertheless, has a very strong resemblance to the eurypterid fragments from other horizons, though the specimens all lack the surface markings characteristic of the eurypterids. Some of the most typical material is figured on plate 25 in the *Bulletin of the Geological Society of America*, Vol. X, 1898, and again in the *Smithsonian Miscellaneous Collections*, Vol. LXIV, No. 2, plate 22.

Of the conditions of sedimentation prevailing during this period Walcott says:

"Briefly summarized, the Algonkian period in North America with its great epicontinental formations was a time of continental elevation and largely terrigenous sedimentation *in non-marine bodies of water*, and of deposition by aerial and stream processes in favorable areas. . . . .

"The North American continent was larger at the close of Algonkian time than at any subsequent period other than possibly at the end of the Cretaceous, when the land was equally extensive. Indeed. it is highly probable that its area was greater then than even now, for no marine deposits of Algonkian age containing pre-Cambrian life, as they were laid down in Lipalian[1] time immediately preceding the Cambrian period have been discovered on the North American continent or elsewhere, so far as known" (290, 81, 82).

Walcott does not wholly subscribe to the fresh water habitat of these eurypterids early for he speaks of *Beltina danai* as "possibly of marine derivation" and uses the presence of this fossil in the Belt Terrane as an indication that a connection of the Cordilleran geosyncline with the sea was temporarily effected allowing "at least a crustacean, and a few annelids" to become adapted to the Montana-Alberta sea. It is clear that Walcott allows this entrance of the sea into the Beltian lake only in order to account for the presence of the eurypterids and annelids and to conform to the prevailing opinion that the early eurypterids were marine organisms. This concession

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[1] Lipalian is a term proposed by Walcott in 1899 "for the era of unknown marine sedimentation between the adjustment of pelagic life to littoral conditions and the appearance of the Lower Cambrian fauna. It represents the period between the formation of the Algonkian continents and the earliest encroachment of the Lower Cambrian sea" (290, 82).

seems to be unnecessary. The annelids surely would be more naturally accounted for as terrestrial forms and besides, it would scarcely be possible for them to leave their trails in deposits formed under water. Such trails would have to be made on surfaces exposed to the air long enough to harden and to be covered by wind-blown sand or dust or by a fresh deposit of water-laid material, but in the latter case a sufficient length of time would have to elapse to allow of the thorough hardening of the trail. In this case as in many another the question must be raised: Why if the eurypterids were marine were they the only organisms which were carried in from the open sea? It is well known that the littoral waters of the Pre-Cambric must have teamed with all the forms of life which are so abundantly represented in the advancing Cambric waters. It seems absurd to suppose that thousands of fragments of a eurypterid should have been washed in from the sea, but no other marine form.

The great thicknesses of Algonkian limestone found in the Belt terrane and corresponding formations have been adequately accounted for by Walcott as algal deposits in a series of lakes formed within the Cordilleran geosyncline. "The lakes of Algonkian [Pre-Cambric[2]] time were not much if any larger in area than the 'Great Lakes' of the St. Lawrence drainage basin and they were much shallower and more laden with mud and mineral matter in solution.

"The area of the Belt terrane in Montana is about 6000 square miles. This seems large when studying it in the field, but it is only one-fifth of the size of our great fresh-water Lake Superior" (**290**, 89).

Walcott has described nine species of calcareous algae from the Newland limestone below the Greyson shales and one which is abundant in the Spokane shales just above the Greyson. It is much more logical to suppose that the Greyson shales represent river rather than marine deposits, for they are coarse and arenaceous with interbedded shales, in which algal reefs could not grow. This would account for the absence of the reefs in the Greyson and for the absence of the eurypterids in the Newland limestone. I make this suggestion merely as a more plausible explanation of the conditions than the one which is usually offered.

If it can be assumed as proved that the remains in the Belt Terrane are of eurypterid affinity, they would offer just the proof

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[2] The Belt terrane is considered by Professor Grabau as representing a pre-Cambric Palaeozoic terrestrial deposit lying above the true Algonkian.

desired to show that the eurypterids from the earliest times lived in terrestrial waters, for the Belt terrane has been shown by Barrell from purely lithological evidence to be non-marine. From the presence of mud-cracks and other structural characters of the formation he concludes that the terrane gives evidence of "two sedimentary cycles, each of which contains a strongly marked formation of mud-cracked red shales, the shales alternating with sandy strata, and both judged to have been deposited on the flood plains of rivers, whose deltas had gained over the subsidence, finally filling up and displacing the shallow epicontinental sea" (**14**, 319, 320).

2. THE NORMANSKILL AND SCHENECTADY BEDS

The Normanskill sandstones and shales of Catskill and the Schenectady bluestones of Schenectady, New York, are so similar lithologically and faunally that they may be considered together. Comparatively little is known concerning the details of distribution of these formations and their physical changes from place to place, yet the descriptions available and the studies I have been able to make in the field, make clear what must be the origin of the sediments. In reference to the Normanskill beds Clarke and Ruedemann make the following statement:

"The lithologic and faunal conditions at the Broom street quarry exposure were found to be a singularly complete duplication of those of the eurypterid-bearing exposures in the bluestone quarries at Schenectady. The Broom street quarry is also a bluestone quarry, the rock being mostly used in the crusher. The courses of 'bluestone' (here an impure argillaceous sandstone) are very compact, from 3 to 30 feet thick between the intercalations of black shales. There is distinct evidence of shallow water conditions, one bed being conglomeratic and largely composed of pebbles, many of which appear to be mud pebbles; another beautifully exhibiting very regular, widely separated wave marks with winnows of comminuted seaweeds and eurypterids in the troughs.

"Quite as in the bluestone quarries of the Schenectady beds, the surfaces of some of the sandstones are densely covered with rather poorly preserved seaweeds and eurypterids. It was therefore natural to expect that here too the black intercalated shales would contain better material of these fossils and possibly also graptolites that would indicate the age of the beds. They have indeed afforded a layer with an association of finely preserved seaweeds, the eurypterids herewith described, and the following graptolites: *Dicellograptus gurleyi* Lapworth, *Climacograptus bicornis* Hall, *Climacograptus bicornis* var. *peltifer* Lapworth, *Cryptograptus tricornis* (Carruthers), the first three forms in great abundance. This graptolite association is one of undoubted Normanskill age. The seaweeds occur in large perfect fronds and are of the same type as those in the Schenectady shale. The eurypterids also are strikingly similar to those from the Schenectady beds" (39, 411, 412).

The eurypterid remains are very fragmentary, in fact, they are so incomplete that generic determinations are only provisional, there being but a few carapaces and fragmentary abdomina with a small number of legs and telsons rarely attached. Five genera are thought to be represented: Eurypterus, Eusarcus, Dolichopterus, Stylonurus by one species each, and Pterygotus by two species, though one of these may be a Eusarcus.

The physical characteristics of the Schenectady beds are closely similar to those of the Normanskill beds. Both consist of heavy bedded sandstones, dark in color, but highly siliceous, alternating with black shales. The sandstones are compact enough to be quarried for building and paving purposes. Both the shales, and bluestones change westward into shales, and eastward become very coarse. In the Normanskill beds pebble layers alternate with the sandstones, while in both formations mud cracks are found in the shales and subsolifluction contortions in the sandstones, structures which show a slumping motion of the sands along the shore (Berckhemer, 21). The sandstones contain eurypterid and plant remains, the latter identified as *Sphenophycus latifolius*, and having a remarkably thick carbonaceous test which is so high in carbon that it will burn. In the shales occur the graptolites and eurypterids, the latter not being so abundant as in the sandstones, but exhibiting better preservation.

The sediments of both the Normanskill and the Schenectady were undoubtedly derived from the east as the following facts indicate: (1) Coarse materials, conglomerates and sandstones with intercalated shales in east along Schenectady-Catskill line, passing laterally into fine black shales westward in the Mohawk Valley; (2) deposits thicker and coarser in east than in west; (3) evidences of shore conditions in sun-cracks, wave marks, and subsolifluction, in east, of conditions in quieter water farther from shore in the fine black shales westward. Appalachia was the only large land area to the east from which siliceous sediments could come, and the characteristics of the sediments just noted clearly point to that continent as the source.

It will probably be readily accepted that the Normanskill and Schenectady are of terrigenous origin, especially since they are several thousand feet thick, but the point which is difficult of determination, is the origin of the fauna of these formations. That the sediments were fluviatile does not at all imply that the organisms in those sediments were also fluviatile. Indeed, it is usually argued that the presence of graptolites and "sea-weeds" in the same beds with the eurypterids is ample proof that all these types of life were marine and that they lived in the littoral zone in the sandy and muddy facies. First, in regard to the "sea-weed" *Sphenophycus latifolius*, there is no reason that I know of why such plant remains could not have been washed in from the land or might not have been living in the rivers, and have thus been swept into the sea. Secondly, it is evident that the presence of graptolites does not indicate deep sea conditions of quiet sedimentation as so often stated. Certainly, there is nothing incompatible with the assumption that the graptolites were spread out on mud flats, or river flood-plains as modern hydroids are, when washed in by the sea. At least the possibility must be granted that the pelagic graptolites would after death be more likely to float near or on the surface of the water until thoroughly decayed and disintegrated, rather than sink to the bottom, and be buried by sediments. In such a case, their only chance for preservation would be through stranding upon some surface where they could be quickly entombed by layers of mud or sand. This line of argument has only just been propounded by Professor Grabau, and while heretical it yet explains many curious occurrences.[3] Thus, although no definite statement can be made at present regarding the precise habitat of the graptolites, we may consider that it is reasonable to assume that their remains are chiefly found in formations accumulating near land especially on delta surfaces. If the graptolite-bearing beds are thin we may suppose that they were formed by frequent inundations from the sea, but when 1500 feet thick, as is the case of the Schenectady beds throughout the entire thickness of which graptolites occur at intervals, then the only interpretation is that the beds were a series of flood-plain and delta deposits, mostly above sea-level, and that the graptolites were stranded on the low-lying land areas by periodic incursions

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[3] Professor Grabau has discussed this subject very fully in his lectures, with especial reference to the Graptolite beds of Europe. He expects to publish soon on this subject.

of the sea. It is often argued that such alternations of sandstones and shales as we see in this series indicate near-shore oscillatory conditions, the shales marking a slight advance of the sea and of fine deposition, the sands marking a retreat and the seaward advance of continental clastics. In the present instance it is difficult to explain the presence of eurypterids as marine organisms if we account for the lithological variation in the customary manner, for it is in the *sandstones* which mark the dominance of terrigenous sedimentation that the eurypterids are more abundant, while they are scarce in the shales which accompany the advance of the sea. If they were living along shore they should be abundant in the shales. The reply may be made that the eurypterids at that time preferred the sandy facies only and that the occurrence of dead individuals or shed exoskeletons in the muds was fortuitous. A phenomenon can hardly be called fortuitous which occurs again and again in response to a given set of conditions. Furthermore, if the eurypterids did live in the sandy facies then there is no reason why their remains should not have been preserved, for it is a mistake to believe that such exoskeletons would be destroyed by the waves, except perhaps on a shingly beach, a facies with which we are not here concerned. A short distance out to sea eurypterid remains would quickly be buried, the hollow case being soon filled by infiltrating sand. Anyone familiar with the occurrence of Limulus exoskeletons on sandy shores knows that they are easily filled by and buried in the sand and that they are preserved in toto, not broken to pieces. Thus we cannot account for the occurrences of the eurypterids on the assumption that they are marine organisms. In the Normanskill beds not a single entire specimen has been found, the whole fauna being made up mostly of carapaces with some separated abdominal segments. In the Schenectady sandstones the conditions are the same, but in the shales the preservation is better.

The evidence clearly militates against a marine habitat for the eurypterids in these two regions and the hypothesis of a fluviatile origin while not yet very strongly supported at least accounts for the observed facts. If the eurypterids were living in the rivers in Middle and Upper Ordovicic time, then it is to be expected that their remains would be carried out to sea. In rivers of moderate gradient it is not so likely that an abundance of remains of fluviatile organisms will be washed seaward, for they may be entirely broken up during transportation, or they may be caught in hollows along the banks, or even buried; but in eastern New York during the later stages of the Ordovicic the streams did not have a moderate gradient. The elevation of the land leading up to the tectonic movement known as the Taconic folding which displaced the rocks in some regions in the Hudson Valley as much as 90° was in progress at least throughout the Upper Ordovicic. One of the results of this movement was the steepening of the gradients of the streams which thus became torrential, not necessarily through increased rainfall, but through increased gradient. The streams consequently brought great quantities of clastic material to the margin of, and into the sea, where deposition probably went on in a sinking geosyncline.

SUMMARY. The physical characters of the Normanskill and Schenectady beds point to Appalachia as the source of the sediments. The mode of occurrence of the eurypterids, graptolites and plant remains is better explained on the hypothesis that the eurypterids and perhaps the plants also were fluviatile and not marine organisms. As yet the Ordovicic merostome faunas are too little known to say that the habitat can be proved to be one or the other; the most that we can say is that all the known facts are better accounted for by the fluviatile hypothesis, which is fully supported by the palaeontological and chorological data.

3. THE SHAWANGUNK CONGLOMERATE[4]

In the intercalated shales in the Shawangunk conglomerate at Otisville, Orange County, New York, and at the Delaware Water Gap and elsewhere a large eurypterid fauna has been discovered. The Shawangunk is distributed in the form of a semi-cone, having its greatest thickness, about 2000 feet, in the Delaware Water Gap region, and thinning away in all directions. That is, it has the form of a dry delta or alluvial fan rather than of a sea coast deposit, for if it were the latter, it would be of fairly uniform thickness and would not have the semi-cone shape. The pebbles in the conglomeratic portion of the Shawangunk are well rounded, but in some sections a certain amount of angularity is still retained as a rule. For river-worn pebbles to be perfectly rounded, they must be transported for a considerable distance. Again the complete destruction of all but the quartz argues for prolonged transportation and frequent reworking. As in the case of the other clastics, there was no source for the

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[4] The lithogenesis of this formation has been discussed in such detail by Grabau (Early Palæozoic delta deposits) that it is unnecessary to give more than a summary here.

conglomerate to the north, south or west, the only possible one being to the southeast where lay the old land of Appalachia. This is also indicated with great certainty by the shape of the cone of this formation which is thickest in the southeast, thinning out to the north, west and south. The material of this alluvial cone could only have been transported by rivers and its river-borne character and deposition upon land are well shown in the frequent occurrence of the torrential type of cross-bedding, and in the absence of any typical marine organisms, such as would be found in the subaqueous portion of a delta. Apparently there was no sea-border portion of this deposit, unless the Pittsford shale is considered as such. The Shawangunk conglomerates found in Pennsylvania and New York, thin away, towards the region of Pittsford shale deposition, but actual connection has not been traced. There can, however, be little doubt that the Pittsford shale represents the finest material brought by the Shawangunk river from Appalachia. This mud was deposited very near the sea border, but there is no evidence that it was deposited in the sea, since the typical marine organisms are absent. It may be that the influx of fresh water was sufficient to keep these out. Interfingering with the shale, are the dolomite beds, deposited during short incursions of the sea (see section 4). If we could trace these Pittsford shales to the northern part of the state or into Canada, we would expect to find them grading into pure marine limestones, but no outcrops are accessible. The black shales intercalated between the conglomerate beds of the Shawangunk at Otisville and elsewhere represent the muds carried down by the river during times of flood. If the eurypterids were living in those rivers, their exoskeletons would have been floated down, while dead and even living individuals would have been swept down by the force of the torrential floods. The exoskeletons and floating bodies would settle down with the mud on the drying up of the water from the flooded areas. That such drying occurred is indicated by the presence of mud-cracks in these intercalated shales. When this mud dried up and became cracked, the eurypterid exoskeletons would be broken up and blown about by the wind, until the fragments should be covered by the next torrential deposit. This breaking up of the tests as the mud dried would account for the fact that the larger eurypterids are always found in a fragmentary condition, while the smaller ones are found whole. How to account for this fact on any other hypothesis is difficult to see.

4. THE PITTSFORD SHALE

This formation is typically developed in the western part of central New York where, in the town of Pittsford, Monroe county, the following section is shown (Sarle, **240,** 1082):

	FEET	INCHES
1. Red shale	6	
2. Light gray, compact, fine-grained, dolomite, with imperfect conchoidal fracture, weathering light brown to cream color		10
3. Soft, gritty mud-rock, purple with bright red mottlings	1	3
4. Dolomite like No. 2		4
5. Purple shale with red mottlings	1	11
6. Green shale	1	2
7. Thin layer dolomite like No. 2		4
8. Black shale, very compact, the base splitting unevenly; grading to olive-green shale in the upper part		10
9. Dolomite like no. 2		10
10. Black shale, with leaf of dolomite ½ inch thick four inches from its base	1	2
11. Dolomite like no. 2		2
12. Soft, green, arenaceous mud-rock, occasionally becoming shaly; the lowest exposed rock of the cut	1	8

The eurypterid fauna occurs in the black shales, Nos. 8 and 10.

A more complete section is shown in the wells of the region, from which the exact location of the fossiliferous black shale beds is ascertainable. The section carries the series down to the Lockport-Guelph horizon.

Salinan

	FEET	INCHES
1. Red shale or marlite	10	
2. Hard, fine grained, yellowish, dolomite, having an imperfect conchoidal fracture	2	
3. Red shale	1	
4. Break estimated at	3	
5. Dolomite like No. 2	3	
6. Green shale or marlite	4	
7. Red shale	1	8
8. Break estimated at about	2	
9. Green shale	2	5

Salinan—Continued

	FEET	INCHES
10. Black shale, very fine textured, fissile, and with 1 inch dolomite parting (eurypterid horizon)	1	6
11. Green shale	1	
12. Dolomite like No. 2	2	
13. Green shale or marlite	6	
From West Branch of Allen Creek		
14. Light colored waterlime, some pyrites and sun cracks	5	
15. Pea-green shaly marlite	7	
	51	7
Niagaran		
16. An impure yellowish porous limestone		
17. Succeeded by an impure bituminous limestone made up of imbricating, shell-like domes, etc		

It is thus seen that there are 41 feet 7 inches between the Lockport dolomites and the Vernon red shales, although there are two initial red beds, Nos. 7 and 3, showing that the red shale sedimentation was already in progress. A comparison of the two sections shows that the first bed of red shale (No. 7) comes at from 2 to 5 feet above the upper eurypterid-bearing bed, while the lower eurypterid bed (No. 10) occurs 21 feet above the typical Lockport-Guelph. In the lower interval are several thin beds of dolomite, and a waterlime showing sun-cracks occurs. The two shale beds are separated by a dolomite bed 10 inches thick, and in the lower black shale is a dolomite parting ½ to 1 inch thick. The thin dolomite beds are often sun-cracked, indicating temporary exposure during formation.

The formations indicate a progressive change of conditions from those of Niagaran (Guelph) time when the widespread Stromatopora reefs were forming and the Guelph fauna flourished, through the period when impure dolomites were deposited in thin, ripple-marked layers containing some marine organisms and "fucoids," followed by conditions favorable to the formation of the impure bituminous limestone, to the final stage of the deposition of the impure porous limestone, 2 feet in thickness and containing a branching organism thought by

Sarle to be a plant. Upon this bed lies the shaly marlite, the first of the lowest Salina or last of Upper Niagaran,[5] and above this a waterlime.

There is thus a marked change in the physical conditions which accompanied the withdrawal of the Niagaran sea and the initiation of the Salina type of deposits. In the lowest bed of the series occurs the last of the Niagaran fauna, *Pterinea cf. emacerata.* In the waterlime (no. 14) the same species occurs, together with a Lingula, *Leperditia cf. scalaris* and an Orthoceras. Then not again till the black shale of the eurypterid horizon, do these forms appear, but it is of great significance that these pure marine fossils do not occur in the eurypterid shale beds proper, but in the thin dolomite partings, and that in these partings the eurypterids are almost entirely wanting. The dolomites were evidently marine, but the conditions under which they were deposited "were not favorable to the eurypterids" says Sarle (**240,** 1086). The question immediately arises: why were the conditions not favorable? and then, where were the eurpterids during the intervals between shale deposition, i.e., during the time of marine dolomite deposition? If the eurypterids were inhabitants of the marine waters or of bays, estuaries, etc., they should be found in the beds containing the littoral fauna of the impure dolomite, for, as has been shown in Chapter III, the faunas of bays and other indentations along the shore are not restricted to such areas, but are much the same as the faunas extending all along a continental shore line. Since the eurypterids were not living in the marine waters, where were they when there were no black muds forming? They appear suddenly in countless numbers representing six species, and they come with the black shale facies and disappear again just as suddenly. Their range, too, is very small. Sarle says: "Though the fine character of the silt forming the black shale and the evidence of interrupted sedimentation noted above, indicate slow accumulation, the occupation by the eurypterids was apparently of comparatively short duration, merely an incursion, as it were, since the black shale all told does not exceed 2 feet in thickness" (**240,** 1086).

To determine where the eurypterids were before their two sudden appearances, one must turn to the source of the black muds. These were not deposited in the open sea, for marine forms are wanting, and in any case, the mud must have been derived from the land. At that time the land to the west, north and south was all covered

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[5] Professor Grabau has recently voiced the opinion, that the Pittsford shales and Shawangunk conglomerate are better considered as the closing deposits of the Guelph period.

by the Niagaran limestones which would furnish pure clastic limestones and not impure siliceous muds. The only area from which the muds could be derived, was the land to the east. That the black mud was merely an extension of the muds forming at intervals on the Shawangunk delta must be obvious when it is seen that in that direction was the only source of the muds and that the Shawangunk muds contain the same eurypterid fauna. This will be more fully discussed in Chapter V.

The areal distribution of the Pittsford is limited. The shale is known from Monroe county and from Oneida county, New York. Both eastward and westward it dies out, the Vernon red shale resting directly upon the Niagaran. In a few localities black shales have been found which have been correlated with the Pittsford, but they contain no eurypterids. Such is the black shale at Buffalo, on Grand Island, and the dark shale in Herkimer county above the Lockport dolomite which contains no fauna except a few Lingulas. The outcrop in Oneida county is at Oriskany creek, where in a bluff occur some dark gray shales, about 21 feet below the base of the Vernon red shale, with intercalated waterlimes and dolomite beds. These dolomites contain fragments of one species, *Eusarcus vaningeni*, together with lingulas and orbiculoideas. Both the areal and vertical distribution, then, are limited, in much the same way as in the Bertie, and the source of this calcareous material may likewise be the same. (See beyond, p. 234.)

If the eurypterids of the Pittsford shale were brought in by the rivers coming from Appalachia, the waters in the region of deposition would become freshened by the inpouring of the river waters, and marine forms would thus be kept out. It is often assumed that the Pittsford shale marks a periodic increase in the salinity of the water, but in that case we are faced by a double problem: if the muds were not deposited by rivers, where did they come from, since they could not have originated in the sea? and then again, the question arises, where did the eurypterids suddenly come from? The muds might be æolian, but not the eurypterids. The only possible conclusion seems to be that the eurypterids and the black muds both were brought by rivers from the land, i.e., that the eurypterids were river-living organisms.

In this connection attention may be called to the fact that the species of eurypterids in the Pittsford and Shawangunk and to some extent the genera as well, are entirely different from those of the Bertie. This is not alone accounted for by difference in age, but is more especially due to difference in origin. The sediment of the Bertie and its fossils came from the continent of Atlantica, and those of the Pittsford from Appalachia. This is more fully discussed in a subsequent chapter (see p. 229).

5. THE BERTIE WATERLIME

The Bertie waterlime of Upper Siluric or Monroan age is confined to central and western New York, and the adjacent portion of Ontario, Canada. It is a gray, fine-grained, argillaceous calcilutyte of a remarkably uniform character, showing practically no variation in texture from place to place. Chemical analysis has shown it to be an impure limestone, high in magnesia, silica and alumina. The following analysis is that of an average specimen (**39**, 101).

SiO_2	11.48
Al_2O_3	17.50
Iron	0.90
$CaCO_3$	42.75
$MgCO_3$	20.35
K_2O	1.00
$NaCl$	0.80
Combined water and loss	5.22

A typical section of the Bertie is exposed at Buffalo where Pohlman has recorded the following succession the lower part being obtained from borings. (See also Grabau, **82**, 115).

Akron dolomite

		Feet
Bertie	Waterlime, about	7
	Shale and cement rock in thin streaks	25
	Tolerably pure cement rock	5
	Shale and cement rock in thin streaks	13
Camillus	Pure white gypsum	4
	Shale	2
	White gypsum	12
	Shale	1
	White gypsum	4
	Shale and gypsum, mottled	7
	Drab colored shale with several thin layers of white gypsum	58
	Dark colored limestone	2
	Shale and limestone	4
	Compact shale	3
	Gypsum and shale, mottled and in streaks, approximately	290 plus

Here we see that the Bertie follows upon the Camillus shales and gypsum, a part of which may belong to the undoubted Salina or Middle Siluric, but the upper part of which certainly belongs with the Bertie to the Upper Monroe, since it contains *Leperditia scalaris*. At Buffalo the Bertie is conformably succeeded by the Akron dolomite, an impure rock 7 or 8 feet thick, containing the Upper Monroe fauna sparingly distributed, and marking the return of normal marine conditions.

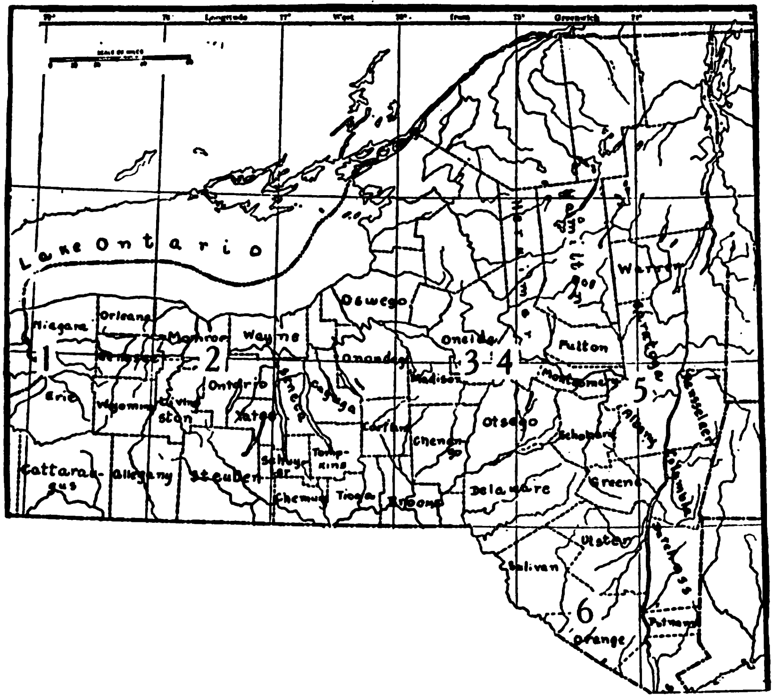

FIG. 2. SKETCH MAP OF NEW YORK SHOWING LOCATION OF IMPORTANT EURYPTERID-BEARING BEDS

1, Buffalo and Williamsville; 2, Pittsford; 3, Waterville; 4, Litchfield and Cranes Corners; 5, Schenectady; 6, Otisville.

In areal distribution the typical Bertie is not a continuous formation, but is found well developed at only two localities; namely, in Erie and in Herkimer Counties, New York, where the sediments were deposited in what Clarke and Ruedemann have called the Buffalo and Herkimer "pools." These two pools or basins are considered to have been of circumscribed area; the Buffalo pool extending from Bertie, Ontario, eastward into Erie County; the Herkimer pool being confined most of the time to the southern part of Herkimer County (See map, fig. 2). In spite of the faunules as a whole having such a restricted distribution, the *Eurypterus lacustris* of the Buffalo region has been found as far east as Union Springs, Cayuga County, although not at intermediate points, and *E. remipes*, the characteristic form of Herkimer County, has been found to the west at Waterville, town of Westmoreland, Oneida County, and still farther to the west in large numbers at Oriskany, Oneida County, at Cayuga Junction, Cayuga County, and possibly even at Buffalo. *Dolichopterus macrochirus* and *Pterygotus cobbi* are common to the two "pools."

THEORIES OF ORIGIN. A careful determination and a thorough understanding of the conditions under which the Bertie waterlime was deposited are essential in the attempt to determine the habitat of the organisms found in that rock. Because no one has yet given an exhaustive treatment of all possible conditions of deposition with a final singling out of the true one; and because, moreover, the answer to this question of deposition furnishes one of the most important lines of evidence concerning the habitat of the Eurypterida, I shall take up a detailed discussion of the subject. Such a fine-grained, stratified rock might have been deposited in one of the following four ways, and these appear to cover all possibilities: (a) by chemical precipitation; (b) by bacterial precipitation; (c) by the formation of an organic accumulation of calcareous shells or plants, or both; (d) by the accumulation of clastic or fragmental material.

(a) *Chemical origin:* That the Bertie waterlime could not have been deposited by chemical precipitation is amply shown by its stratification and especially by its composition. A rock which is a chemical precipitate, is more likely to be massive, never showing such fine stratification as is found in the Bertie, for in the process of chemical precipitation there is no arrangement of the material by currents bringing in fresh supplies which vary slightly in color or texture and which when deposited make the separate layers which produce stratification, since in precipitation the action is more or less continuous and minute crystals are formed which either entirely make up a rock, or else cement into a compact mass, fine particles of clastic material as is the case around modern coral reefs. The texture of a chemical precipitate would be a finely crystalline one, whereas the material of the Bertie does not conform to this, for a thin section of the water lime shows under the microscope an exceedingly fine-grained lime mud, the grains being angular and of varying sizes, with rhombic crystals of dolomite scattered through the mass of calcite fragments. There are also many fine, black specks, probably of carbonaceous material. The most significant fact of the composition, however, is the presence of the silica and the alumina, which forms nearly one-third of the rock. Such a composition is entirely incompatible with the idea of chemical deposition, where we should expect practically pure carbonates.

(b and c) *Organic origin.* If the Bertie were an organic deposit its fine texture would permit of only two types of organisms active in its formation, namely, the protozoa or the algae. The lime content might be supplied by Foraminifera or by lime-secreting algæ, the silica by Radiolaria. The microslide of the Bertie shows no trace of any of these organisms. One other method of organic deposition is possible. The work of Drew, Sanford, and Vaughan has recently shown that in warm or tropical seas certain bacteria are active in precipitating calcareous muds from the sea water. That the Bertie waterlime could not have had such an origin is evident from its chemical composition given on page 106 above, in which the silica and alumina play too important a part, amounting to 28.98 per cent of the whole.

Since the chemical and microscopic study of the Bertie proves the impossibility of either a chemical or an organic origin, we must conclude that the rock is clastic.

(d) *Clastic origin.* A rock of clastic origin may have one of two sources: (1′) it may be composed of material which was originally derived from the sea, that is, it may be thalassigenous, or (2′) it may be derived from the erosion or breaking up of a pre-existing rock on the land, that is, it may be of terrigenous origin.

(1′) Organic material broken up in the sea by organisms, or along the shore by waves, consists of shells, corals, and other hard parts of organisms mixed with varying amounts of sands and muds, organic and inorganic, the composition depending on the character of the rock supplying the detritus. Such clastic deposits are especially well developed around coral reefs where the purely biogenic rocks grade laterally in all directions into the clastic ones. That the Bertie waterlime could not have been a lime mud derived from the erosion of coral or other reefs and deposited in the surrounding quieter water or in the lagoons, as in the case of the similar, fine-grained lime mud forming the Jurassic Plattenkalke of Solnhofen, is shown by the utter absence in this horizon or vicinity of reefs which could furnish such deposits, and again by the presence in the composition of the silica and alumina. In the Bertie the silica and the alumina is intimately mixed with the lime, as is shown by the relative constancy in composition and character of specimens from different parts of the formation. In the Plattenkalke of the Solnhofen, on the other hand, where the siliceous material represents the impure dust blown from the land, it is found in clayey layers (*Fäulen*) between the thin bedded (*Quicksteine*) and thick bedded (*Flinze*) limestones, and not in intimate mixture with the other constituents, as is the case in the Bertie (**293**, 144, 209).

(2′) The only remaining source of the deposit is the land, from which clastic material might be brought by the wind or by the rivers. If brought by the wind and deposited far enough from shore to be free from coarse material, the deposit would not have a circumscribed areal distribution. Such a restricted distribution is, however, possible if the material has been supplied by the rivers. If carried into the sea, it may be deposited in quiet water, and this may produce such a fine-grained rock as the waterlime, which is free from coarse clastics. Such regions of deposition would be found either far out at sea where all of the nearer-shore, coarser clastics were absent, or else near the shore, but in sheltered bays. If these river-borne muds were not carried into the sea, then they must have been deposited on land in the river flood-plains.

We may consider for a moment the possibility of this formation having been deposited at a sufficient distance from land to allow of the quiet accumulation of fine sediments, or else in sheltered areas along shore. Such deposits at the present time are represented by the blue or slate-colored muds, and these are the ones which are spread over the floors of shallow seas and out to the edge of the continental shelf. Murray and Renard (**194**) have estimated that these muds cover 14,500,000 square miles of the ocean floor. An average analysis shows the following composition:

Ignition	5.60	$CaCO_3$	2.94
SiO_2	64.20	$Ca_3P_2O_8$	1.39
Al_2O_3	13.55	$CaSO_4$	0.42
Fe_2O_3	8.38	$MgCO_3$	0.76
CaO	2.51		
MgO	0.25		100.00

A comparison of this analysis with that of the Bertie shows that the two types of deposits are as different as could well be imagined, the deep sea mud having combined alumina and silica 77.75 per cent, as opposed to 28.98 per cent, while the combined CaO and MgO is 5.00 per cent as compared to 63.10 per cent in the waterlime. One cannot argue much, however, from this pronounced difference between the two types, because it must be borne in mind that in the late Siluric the greater portion of exposed land areas in northern and western North America was covered with limestones or dolomites and that in consequence the muds which accumulated far out to sea, and which were the finest particles derived by the erosion of those land surfaces, would of necessity have been high in calcium and magnesium, whereas the blue muds accumulating in our present oceans are derived from a great diversity of rocks in which the limestones form a very small part. Thus, while we can find no analogous mud deposit in modern oceans, we are not justified in saying that such a one might not have formed in the past under different conditions; and I can, therefore, see no characteristics in the chemical composition of the rock to preclude the possibility of its deposition at a considerable distance from land. We are not, however, lacking in another criterion when the physical characteristics fail to be restrictive; the type of fauna represented is the safest guide in the interpretation of ancient regions of deposition. There is no region where muds are accumulating in the sea today, whether near shore or farther from land, where an abundance of organic remains is not being included. Along the entire Atlantic coast of North America the muddy facies of the littoral zone swarms with life, and while many of the species are confined to that facies it certainly cannot be claimed that where muds are accumulating there is a paucity of plant and animal life. Detailed studies of restricted areas of the ocean floor have proved that a large and varied fauna flourishes even where muds pour in in great quantities from the land. Thus, Walther (**295,** 36) has found that the muds in the Bay of Naples contain a fauna of about 1120 species of invertebrates and fishes. The fauna of the Bertie contains not two dozen species and nearly all of these belong to one phylum and to one class in that phylum, namely, the merostomes. Such a fauna cannot be considered as marine in any sense, if we accept the principles for the criteria of fossil faunas, based upon the study of recent faunas (p. 67 above). It is characteristic of no portion of the seashore, bays, lagoons, or estuaries, nor of the open sea, whether in the littoral belt or the deeper sea; such a fauna finds its counterpart in no waters of normal marine salinity, nor yet in those of modified marine salinity, either estuaries, epi-continental seas, lagoons, or other brackish to fresh water dependencies of the ocean. Thus, though we cannot determine with certainty the place of deposition of the muds from the chemical composition, or from other lithological characteristics, the fauna indicates with absolute certainty that those muds were not deposited in any portion of the sea.

From the foregoing discussion it appears that the Bertie waterlime is best interpreted as a deposit of clastic origin, and that the material was transported by rivers. It also appears that this material could not have been deposited in any part of the sea, for it has not the characters of non-terrigenous deep sea muds, nor the faunal content of a near shore, bay or estuarine deposit. There remains but one place for the deposition of these terrigenous muds and that is upon the land. There seems to be no escape from the conclusion that these lime muds of the Bertie represent the flood-plain or delta deposits from one or more rivers, or else that they accumulated as playa lake deposits. The characteristics of the sediments and faunas of such deposits have been fully described on pages 79-83, and it must be conceded that of all the known modes of deposition the lower flood-plain and upper delta regions of rivers come nearest in their physical and faunal characters to those found in the Bertie waterlime, though, of course, the nature of the sediment demands a source of supply in which calcareous material plays a dominant rôle.

It should be noted in this connection, that shallow water conditions of deposition for the waterlimes of New York and the associated calcilutytes (Manlius, etc.) are indicated by the occurrence of sun-cracked layers at several points. While these have not been found in the Bertie of the Buffalo region, they are wonderfully developed in the waterlimes of the Rosendale-Rondout regions, and in the Manlius of central New York and elsewhere.

Considering the waterlime as a flood-plain deposit, the history during Bertie time would be something like the following:

The early Siluric history of the eastern part of the North American continent had been admirably staged to lead up to the climax of waterlime deposition in many regions during the later Upper Siluric. During the Niagaran there had been a widespread advance of the sea which undoubtedly covered most of southeast and central Canada, as we may judge from the remnants still to be observed in the Lake

Temiscaming region and elsewhere. At the base of the series is the Clinton followed chiefly by shales and limestones representing the Rochester and Lockport, and finally by a dolomite. Since the sea in which these deposits accumulated was a transgressing one, it is apparent that in some sections the Niagaran deposits would overlap the late Ordovicic deposits and come to rest directly upon the crystallines of the Canadian shield. Furthermore, progressively higher members of the Niagaran would come to rest upon the old land as the Niagaran sea continued to spread. By the end of Lockport time, the greatest expansion was reached, and contraction of the sea set in, the Guelph dolomites being deposited in this more circumscribed sea. In some sections the change in deposition is inaugurated by the argillaceous beds of the Eramosa formation, and some of the late Niagaran beds are somewhat argillaceous. Beyond the farthest line of expansion of the Niagaran sea, the crystallines continued to form the rocky surface of the land. The contraction of the sea continued, until by the beginning of Salina time it had shrunk to such an extent that only a small epi-continental sea remained. It makes little difference whether we assume that this sea dried up entirely during the period when the salt formed in central and western New York and in Michigan, or whether we believe that the contracted remnant of the Niagaran sea persisted, the greater part of the North American continent is known to have become dry land during Salina time. Many writers have pointed out the evidences of arid conditions in the Salina, and I need not here repeat them. The entire country was exposed to drying winds, rain fell but seldom, and then it came as cloudbursts, filling river channels quickly and creating torrential streams of short duration. Whatever vegetation there may have been upon that ancient land was destroyed by the heat, and we may picture the country as a great desert where desiccation was in progress and where the winds and the rivers of flood seasons were the chief agents of transportation for the mechanically broken up rocks. The Salina was by no means a period of short duration; the thickness of the salt deposits alone shows that a long time was required for their formation. Throughout this whole period, disintegration of the Niagaran and earlier limestones was in progress, until there must have been piled up great limestone and dolomite dunes with fine beds of impure clayey material wherever shales were exposed to the clastation processes of the semi-arid climate. The crystallines likewise suffered the same destruction, and they added their quota to the materials which were blown about in one of the earliest deserts recorded in the history of the rocks. This desert differed markedly from all the large ones which are known to us at present, in having a predominance of carbonates instead of silicates in the "sand" grains. We must not, however, push the doctrine of uniformitarianism too far and insist that all the deserts in the past must have been composed of siliceous grains, because that is the rule in modern large deserts. On a small scale limestone deserts are forming now, and if large areas of limestones could be exposed in the arid regions of Africa or Arabia these limestone deserts would form on a vast scale. But there is now too much diversity in the rocks of the earth's crust, because throughout most of the world the continents have in large part been above sea level during the Tertiary and Quaternary, and erosion has been going on so that many types of rocks are exposed and particularly large areas of crystallines, and when any or all of these are brought under arid climatic conditions, grains of a great range in composition are exposed to the sorting action of wind. In the Middle Siluric of North America, on the other hand, a land area which had been covered by limestone was subjected to arid conditions, and there is no escape from the fact that dominantly lime grains were formed by the prolonged exposure during which mechanical processes alone were active, and decomposition played no part.

Succeeding the arid or semi-arid climatic conditions of the Salina was a period of greater rainfall and of expansion of the epi-continental seas. The rivers became permanent in response to the rains of a pluvial climate, and there followed upon the period of rock destruction in situ a period of transportation of material from the land into the sea. The prolonged disintegration of the limestones and dolomites with local shales had provided a vast soil covering which must have extended to a considerable depth, and which, because of fineness and friability could easily be removed by streams. Even the weakest little rivulet would be able to carry a small load of this material, which was so conveniently prepared. With the increased moisture in the air decay became active in further breaking down the mechanically disintegrated rocks, and in this way the igneous rocks that were exposed through erosion would yield a certain amount of silica and alumina as would also the shale bands in the limestones. Thus, while the rivers carried material which was dominantly calcareous or magnesian, certain impurities were also included. Some difficulty has been offered by the high amount of alumina, to account for which I offer the following suggestion. The only decomposition product in which alumina is higher than silica is laterite which might have been formed either during the Salina, to the north of the desert in which the limestones were disintegrating, or else during the Monroan when the arkoses previously formed by mechanical breaking up were subjected to decomposition. That the northeastern portion of Atlantica was of a more pluvial character than the northern part which supplied the lime mud is independently inferred from the character of the deposits formed in western Europe at this time. For here the semi-arid conditions existed on the *eastern* side of the highland which supplied the sediment, indicating that the moist region lay to the west, where the great southward flowing rivers of Atlantica appear to have had their source.

So far it has been shown that the Bertie waterlime is of clastic origin, and that the sediments were river-transported from the north. The fine stratification of the deposit and layers of sun-cracks in certain localities are structural features indicating that the muds were deposited in quiet waters, while the nature of the fauna has shown that the place of deposition could not have been in the sea, either far from shore, or in any protected, littoral portion; the only remaining place is on the land. In concluding this discussion, therefore, we may test the hypothesis of the flood-plain or delta origin of the Bertie by determining whether it accounts for all the facts. We are to imagine, then, two rivers flowing from the low-lying Canadian area southward until they empty into the slowly-advancing Upper Siluric sea. Marine deposition would be active to the south and if the rocks now covering the Monroan in southern New York and northern Pennsylvania were removed, we would expect to find the mixed marine and freshwater beds which marked the interfingering of the delta deposit with those that were laid down in the sea. Unfortunately, at present we know only the marine Monroan limestones from Pennsylvania, the position of that ancient strand-line being nowhere exposed. If we bear in mind the fact that the outcrop of the Bertie waterlime in New York forms only a narrow belt extending east and west, it is readily understood that the cross-sections of the two eurypterid-bearing "pools" are to be interpreted as cross-sections of the two north-south river channels (see figs. 3 and 4). The northward extension of those river courses has been removed by subsequent erosion, the southward continuation to the strand line is covered by later strata. If the Bertie waterlime of the two "pools" represents muds really deposited on flood-plains or the lower reaches of two rivers, then the lithological peculiarities of the deposit are readily explained. In that case we would expect these muds to become more marine southward, where they are now covered, and where the subaqueous delta part was situated. Between the deltas the Bertie should be impressed with certain marine characters, as it actually is in sections in Cayuga and Ontario Counties. In the Auburn-Geneva quadrangle, Cayuga County, the Bertie is an evenly bedded, impure, magnesian limestone, which when freshly broken is dark colored and of medium hardness. In portions it shows faint deposition lines, but heavier layers, from one to two feet thick, are usually quite compact. Some layers weather into a hard slaty shale. The fossils which have been found are: a few Lingulas, two species; one Orbiculoidea, a Rhynchonella, *Leperditia alta*, and fragments of eurypterids. In the Canandaigua-

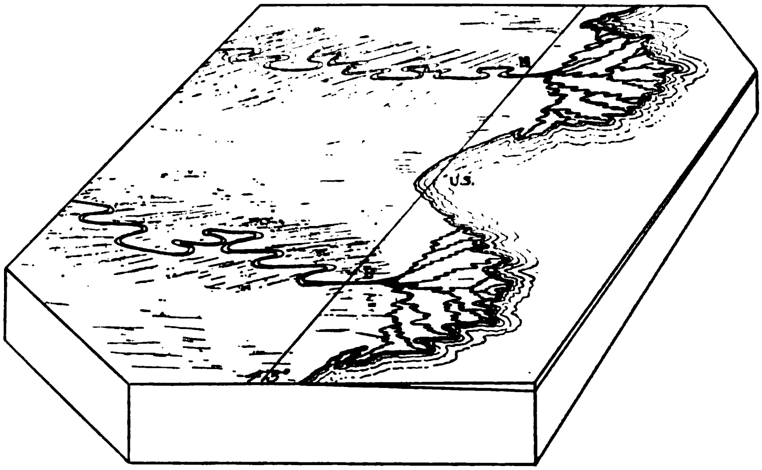

FIG. 3. BLOCK DIAGRAM ILLUSTRATING THE TWO PRINCIPAL DELTAS OF BERTIE TIME

B, Buffalo; U. S., Union Springs, H, Herkimer.

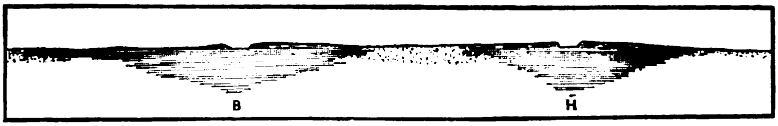

FIG. 4. CROSS SECTION (ON THE 43RD PARALLEL) OF THE BERTIE AND HERKIMER DELTAS

Naples quadrangle, Ontario County, the Bertie is a hard, dark, impure, hydraulic limestone, occurring in thick layers separated by thin seams of dark and apparently carbonaceous matter. The waterlime here shows a gradual transition from the Camillus. Fragments of eurypterid heads and appendages are not uncommon, and frequently *Leperditia cf. alta*, *Whitfieldella laevis*, and *Leptostrophia varistriata* occur. Yet the marine shells in both cases are seen to be of small specific gravity such as would easily be floated in across mud flats, and they evidently do not constitute a typical marine fauna since too few forms are represented. These occurrences of two or three species of brachiopods and of a crustacean in certain localities, far from proving that the Bertie as a whole was deposited in the littoral district of the sea, shows very clearly that the greater part of the waterlime was not deposited in any part of the sea and that only at intervals were a few marine organisms washed inland. Another significant fact that has already been referred to in connection with modern deposits is the separation of marine and fluviatile faunas in distinct layers. When river water meets with the invading tide, the current is checked and held back; this slack water is still fresh, and it deposits its load of mud and organic remains *above* the reach of marine waters. If marine currents later overcome the river currents and pass up the stream channel, marine organic remains may be deposited over the freshwater ones. Such lightweight structures as the exoskeletons of fluviatile crustacea and other arthropods are probably seldom carried out to sea against the opposing, denser salt water. If the eurypterids were fluviatile, the occurrence of their remains in abundance and well preserved in the regions where marine fossils are absent, and their scattered occurrence in the localities where a few brachiopods have been found is easily explained. Their entire absence from the Rosendale waterlime and the appearance of only a single specimen in the Rondout is likewise explained, since these deposits show a more marine character than does the Bertie of the Buffalo and Herkimer regions. The river portions of the Rondout and Rosendale either are not uncovered or else have been removed by erosion.

SUMMARY. The only available source of the lime in the Bertie is from the muds derived by the erosion of an older magnesian limestone, the Niagaran, or in some cases, perhaps, the Trenton. Where the Bertie is eurypterid-bearing, the rock was evidently deposited above sea-level, as a river flood plain and subaerial delta deposit. Southward and laterally the subaqueous part of the delta carries few or no eurypterid remains, but more marine organisms. That the Bertie eurypterids lived in the rivers is thus indicated, while their absence from the Rosendale could be explained by assuming that the present exposures of these rocks are in the more marine portion of the deposit. The relations are shown in the following diagrams (figs. 5 and 6).

6. THE KOKOMO WATERLIME

The Kokomo waterlime of Indiana is of very much the same character as the Bertie waterlime, showing the same thin laminations and fine texture. Throughout a limestone series forty feet thick thin waterlime layers occur and it is in these alone that the films of eurypterid exoskeletons are found. In the pure limestones a brachiopod fauna occurs, but no eurypterids are present; while in the separating waterlime eurypterids and ceratiocarids, but no brachiopods are found. Foerste has made the following statements in regard to the occurrence: "At the McReynold or Interurban quarry, in the southwestern corner of Kokomo, there is a much thicker exposure of the upper or brachiopod horizon. No merostomata have been found here.

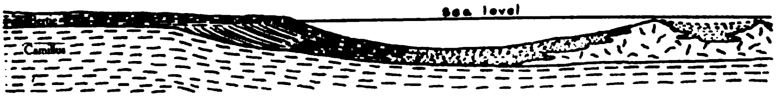

FIG. 5. IDEAL N. W.-S. E. CROSS SECTION FROM BUFFALO, N. Y. TO TYRONE, PA., SHOWING CONDITIONS DURING BERTIE TIME

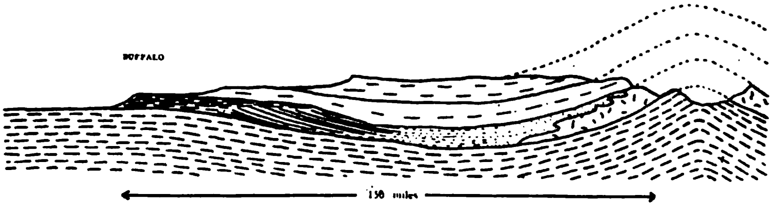

FIG. 6. GENERALIZED CROSS-SECTION OF THE SAME REGION SHOWING PRESENT CONDITIONS DUE TO POST-BERTIE DEPOSITION AND EROSION

"South of the center of Kokomo within the town limits, there is a deep quarry, covering a considerable area, where merostromata are common at an elevation of 3 to 3½ feet above the base of the quarry. This belongs to the lower thinly laminated part of the section, and the richly fossiliferous brachiopod beds appear to be absent" (Foerste, 67, 7).

A section at the old George W. Defenbaugh quarry southeast of Kokomo, Indiana, shows the exact relation between the eurypterid-bearing layers and the brachiopod bed (67, 7).

	FEET	INCHES
Heavy bedded fossiliferous limestone	1	8
Chert, thin, bedded, with ostracods		1
Thin bedded fossiliferous limestone	2	
Base of brachiopod horizon		
Darker layer of limestone		2
Thin bedded limestone		10
Heavier bedded limestone, but thinly laminated	1	4
Thin bedded limestone		9
Darker limestone		3
Layer with merostomata		

The line of reasoning which was adopted to show that the Bertie was a clastic, river-borne deposit which was spread out on the land

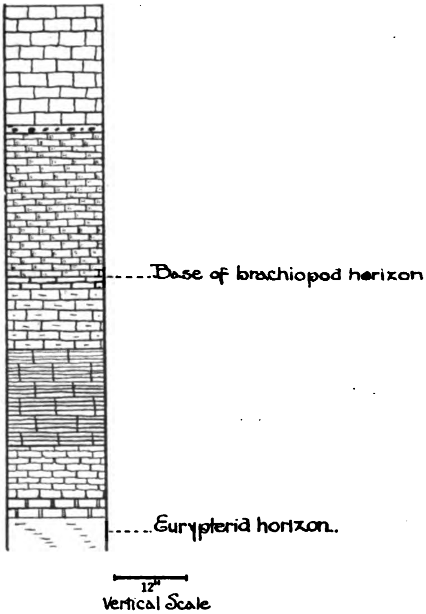

FIG. 7. SECTION SOUTHEAST OF KOKOMO, INDIANA, SHOWING DISTINCTNESS OF BRACHIOPOD AND EURYPTERID HORIZONS
(Data from Foerste)

can be followed through in the same way for the Kokomo, the most marked difference between the two formations being the local character and diverse source of the latter. The Kokomo waterlime lacks the lateral and vertical persistence characteristic of the Bertie and in this respect is similar to the waterlimes of Oesel which in many outcrops appear as thin bands intercalated between limestone beds (see section, fig. 7 above, and description). Indeed, the section revealed at Kokomo is the counterpart of what theoretically we should expect to find in the southward continuation of the Bertie in Pennsylvania where the waterlimes merged into the marine deposits.

The second difference between the Kokomo and Bertie waterlime is that of origin, for while the latter was derived from the north the former must have come from the west since the sea covered the Michigan area during Monroe time and precluded the derivation of sediments from the Canadian region. It is difficult to arrive at an explanation of the lithogenesis of such a formation when so few outcrops are visible, but yet we can determine enough to show that the Kokomo sediment was river-borne and came from a continent to the west (see map, fig. 8). A study of the faunas convincingly shows the distinctness of the source of the material and organisms found at Kokomo (see below, pp. 253-256).

7. THE TARANNON-WENLOCK BEDS OF SOUTHERN SCOTLAND

Distribution of Formations. The clearest conception of the lithogenesis of the eurypterid-bearing Wenlock beds of southern Scotland is to be obtained from a survey of the palaeographic conditions existing in Great Britain from the end of Ordovicic time on through the Siluric. The outcrops in Wales, in the hilly areas of Cumberland and in innumerable outliers in Westmoreland and elsewhere, as well as those of the southern uplands of Scotland, indicate that throughout the Ordovicic the sea covered Wales, the greater part of western and central England and southern Scotland as far north as the great northeast-southwest fault line delimiting the northern edge of the tableland. The central and northern portions of Scotland formed a part of the old land which, rising to the east in the Scandinavian shield, extended westward through North Britain and Ireland on into the northern Atlantic, and which throughout the Palaeozoic furnished the sediments which were deposited either in the sea to the south of that ancient shoreline, or on the land to the north of

FIG. 8. PALAEOGEOGRAPHIC MAP OF NORTH AMERICA DURING BERTIE TIME (Grabau)

it. While the faunas and the lithological deposits in England and Wales indicate, with few exceptions, the prevalence throughout the Ordovicic of open marine conditions, in southern Scotland, on the other hand, the record is one of oscillations, showing now the prevalence of terrigenous deposits, again that of sea-derived or thalassigenous deposits.

A rapid survey of the succession of events during Ordovicic time shows that there was a gradual retreat of the sea towards the south and southeast during the middle and upper Ordovicic and the lower Siluric, followed by a widespread advance during Wenlock time. A few of the typical sections will readily bring out these facts (see also the general description of the region on p. 151).

The Ordovicic and Siluric rocks of the Southern Uplands of Scotland are exposed in a series of belts trending northeast-southwest. The southernmost is a rather narrow, discontinuous strip composed of Wenlock and Ludlow flaggy grits and mudstones, bordering the northern coast of Solway Firth and extending northeast into the Cheviot Hills. The second belt, from 20 to 25 miles wide extends from St. Abbs Head on the east coast, through the Lammermuir Hills across the greater part of Selkirk, Peebles, Dumfries, Kirkcudbright and Wigtown (see map). This band consists of the Lower Siluric Llandovery and Tarannon beds. The third belt, narrow in the east where it does not quite reach the coast, but constituting the northern slopes of the Lammermuir Hills, broadens westward until it becomes 15 or more miles wide. It consists of Llandeilo and Caradoc limestones with a large amount of radiolarian chert of Arenig (Lower Ordovicic) age. The northwestern termination of this belt is the Girvan area with its great development of Arenig volcanic rocks. From 5 to 10 miles north of the third belt are two important regions one in the Pentland Hills, Edinburghshire, the other in Lanarkshire, where the Wenlock, Ludlow and Downton beds are exposed as inliers in the Old Red sandstone. The relation of these isolated Siluric outcrops to those of the southern tableland will be made clear by a consideration of the tectonic arrangement.

Towards the close of the Lanarkian a pronounced uplift took place accompanied by a tremendous amount of lateral compression giving a great series of folds whose axes run northeast-southwest, parallel to the major axis of the tableland. Denudation set in before the beginning of Old Red deposition so that the Old Red rests unconformally upon Siluric or Ordovicic beds. Moreover, formations which were continuous at the time of deposition now appear in far separated localities. Over the whole of this much folded and faulted series the Old Red sandstones were deposited by the rivers flowing south from the northern Highlands. Subsequent erosion has carried away large portions of these Devonic beds, and has cut down into even the lower rocks, so that the Ordovicic and Siluric are exposed in broad belts as shown above, while in certain places only inliers in the Old Red have as yet been exposed. To this class belong the isolated outcrops in the Pentland Hills and in Lanarkshire. It is thought that in all probability the Wenlock and Ludlow in those regions were continuous and extended southwest into Ayrshire and northeast into the Lothians.

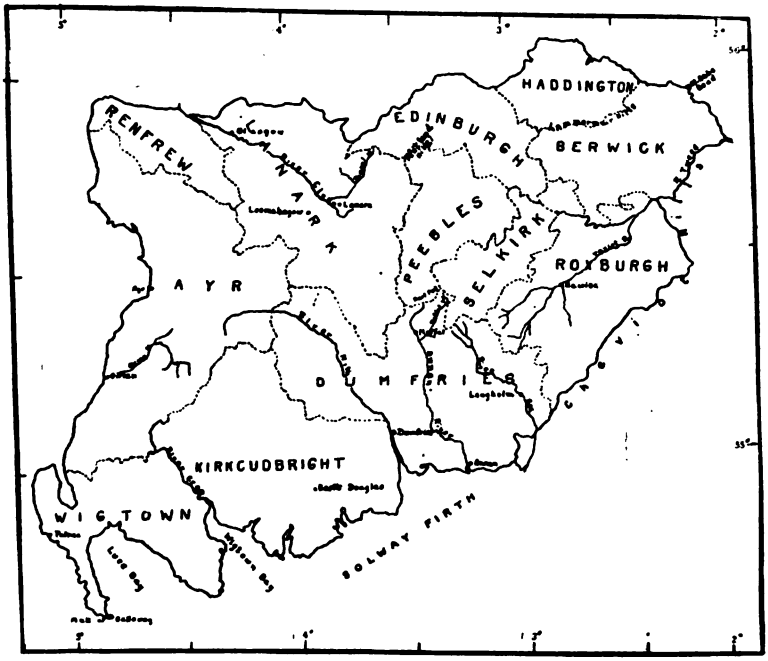

Fig. 9. Sketch Map of Southern Scotland Indicating Localities for Ordovicic and Siluric Eurypterid-Bearing Horizons

The Llandovery-Tarannon. In the lowest Ordovicic, volcanic activities were pronounced in the Girvan area, but throughout the central and northern belts of the tableland open marine conditions prevailed, marked either by submarine volcanoes or by the accumulation of radiolarian ooze, but the presence of fossiliferous mudstones in the northern belt of Arenig rocks indicates that the shore was not far distant. There is evidence that during Llandeilo time conditions were less stable in the northern area, for the black graptolite-bearing Glenkiln shales (Upper Llandeilo) often merge laterally into greywackes and grits, while sometimes, as for instance in sections at the headwaters of the Girvan River, the Glenkiln fossils occur in "minute dark seams in sandy shales, embedded in massive greywackes and grits" (Peach and Horne **215**).

The section which is most complete, showing no disconformities and indicating, therefore, continuous deposition, is that at Moffatdale about 10 miles to the northeast from Moffat, where in the famous Dobb's Linn anticline studied by Lapworth, the succesions given in the first column, figure 10, is shown. It will be seen that the Glenkiln and Hartfell groups (Llandeilan and Caradocian, respectively), are complete and that the latter is followed by the Birkhill shales (Llandovery) which end with the *Rastrites maximus* zone (b3), which in turn is conformably followed by the green and grey shales of the Lower Tarannon. Crossing the strike to the northwest for about five miles, the Hartfell section is met with. It is the type locality for the shales of that name. The succeeding Birkhill shales are found to go no higher than the *Monograptus gregarius* zone (a3), which is conformably followed by the Tarannon grits. The signifi-

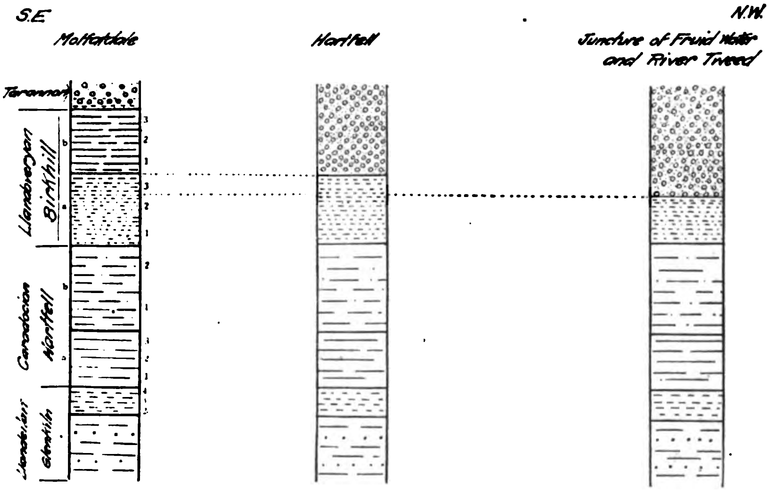

FIG. 10. COLUMNAR SECTIONS OF ORDOVICIC IN MOFFAT DISTRICT, SCOTLAND

cance of this succession will be spoken of presently. Continuing at right angles to the strike, there is found about 2 miles northwest of Hartfell on the Cow Linn, the last outcrop of the *Monograptus gregarius* zone. Only 3½ miles northwest of this locality, near the junction of the Fruid water with the River Tweed the *gregarius* zone is no longer to be found, the highest of the Birkhill beds being the *Diplograptus vesiculosus* zone (a2) which is the second in the Lower Birkhill series. This zone is immediately followed by the Tarannon grits. As the last of the Llandovery outcrops are traced towards the north, fossils become very rare indeed and, although towards the boundary line of the northern and central belts no specimens of *D. vesiculosus* or of *D. acuminatus* have been found, a few other graptolites which along the valley of the Tweed are associated with these zonal fossils, have been encountered. It is thus seen that within the remarkably short distance of 9 miles,[6] as traced from the Dobb's Linn anticline to the Llandovery-Tarannon border, the whole of the Upper and nearly all of the Lower Birkhill shales have disappeared, the fossils becoming rare even in the shale members which are found, and, most significant of all, the Tarannon grits or conglomerates everywhere follow upon whatever member of the Birkhill group forms the top of the section.

Such a stratigraphic relation might be interpreted in one of two ways. On the one hand it might be supposed that the Llandovery sea retreated to the southwest and that dry land conditions accompanied by subaerial denudation obtained in the areas laid bare. This would imply that more of the Birkhill shales had been deposited to the northwest of Moffatdale than are now seen in the sections and that the present exposures represent merely the parts which have not been touched by erosion. The Tarannon would then represent the river deposits spread out upon the eroded remnants of the Llandovery. That such is in all probability not the case is indicated by the statement made by Peach and Horne that in the Hartfell section (in the Frizzle Burn) "the black shales and mudstones of the *Monograptus gregarius* zone pass conformably upwards into the massive grits of Tarannon age without any representative of the Upper Birkhill Shales" (P. and H. **215,** 133). The significant word is *conformable.* If the contact is conformable there was no erosion, and therefore it is not likely that two miles distant there was any considerable erosion. Thus another interpretation is called for. The facts, and they have

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[6] The distance would, of course, be much greater were the folds eliminated.

been gleaned from a detailed study of many more sections than can be mentioned here, lead to the conclusion that there was no erosion between the deposition of the last of the Llandovery (Birkhill) beds, whether they were Lower or Upper Birkhill, and the lowest Tarannon beds. The structural relation is, therefore, one of replacing overlap, the Tarannon beds pushing to the southeast just as rapidly as the graptolite-bearing Llandovery muds retreated in the same direction. Lines of sections at right angles to the strike of the Llandovery and Tarannon rocks taken in various places from coast to coast, indicate that in the northern part of the central belt the Tarannon is always of a massive unfossiliferous character, grading southeastwards into graptolite-bearing shales and mudstones. There is no doubt that the coarse conglomerates and grits were river-borne. In one of the typical localities in the Moffat district Peach and Horne, in describing the conglomerate say, "the rock possesses a greywacke matrix, in which are embedded rounded pebbles of quartz, red chert with radiolaria, Arenig volcanic rocks, with boulders of granite and quartzite from eight to ten inches in diameter. Some small pieces of mica schist have also been observed. The fragments of quartzite and mica-schist resemble rocks of those types in the Eastern Highlands; there can be little doubt that they were derived from that region" (P. and H. **215**, 210). These authors also note in regard to the greywackes and grits that, "both volcanic and plutonic rocks have contributed to their formation. The fragments are angular or subangular. Well-rounded grains are rare. There is, further, a very great variability in the sizes of the constituent grains; indeed, the material does not appear to have been well sorted by aqueous action" (**215**, 211). It seems surprising that materials which had been transported by rivers for so great a distance, it being about one hundred miles from the Eastern Highlands to the Moffat district, should not be better sorted. However, it is clear that the material must have been brought down by rivers. That it was deposited as a subaerial delta or series of deltas which spread out into the sea to the southwest is suggested by the character of the materials, for in the extreme north of the Tarannon area there are only the coarse conglomerates without fossils, but these deposits merge ever so slowly into finer ones southward, the first change in the conditions of sedimentation being indicated by the intercalation of thin, leaf-like beds of shales bearing graptolites. Indeed, this domination of terrestrial over marine sediments is seen even towards the close of the Llandovery in many regions. In the northeastern portion of the Central Belt in the basin of the Gala Water, the various Birkhill zones are separated from each other by thick beds of grits, conglomerates, and greywackes. Even the graptolites show the effects of the great inpouring of fresh water, for not only are they rare, but those which are found are dwarfed as would be expected of a fauna dwelling in brackish water. Such features point beyond a doubt to the oscillatory conditions which prevailed along the shoreline and just so far as those conditions can be traced southward so far may we say the sea retreated in Llandovery and Tarannon time. It is only along the south central portion of the southern margin of the Central Belt that the highest Tarannon rocks are found; their continental origin is undoubted. They are unfossiliferous except for tracks and trails and they consist of grey, green, and red shales with bands of conglomerates one or two feet thick. All of these facts indicate a lithological replacement of marine by terrestrial deposits along a northwest-southeast line. The faunal replacement is equally striking. Along the northern border of the Tarannon belt the coarse deposits contain no fossils, but tracks and trails; when a few dark shale bands appear, they usually contain not good zonal fossils but a mixed Llandovery and Tarannon fauna. *Monograptus exiguus* is recognized as the lowest graptolite in the Tarannon and yet it frequently occurs with *Rastrites maximus* and *Climacograptus normalis*, the former of which is the zonal fossil for the uppermost Birkhill, and both of which are typical Llandovery forms. Towards the south, however, this interfingering and mingling of faunas is no longer noticeable and the Tarannon passes into the shaly, mudstone phase where zonal graptolites are well recognized, though in the passage to the upper Tarannon the mud facies is again replaced by conglomerates. The evidence supplied by the lithological and faunal characteristics, each taken independently, points conclusively to a replacing overlap and to the terrestrial origin of the Tarannon. The facts may be set forth in a generalized section.

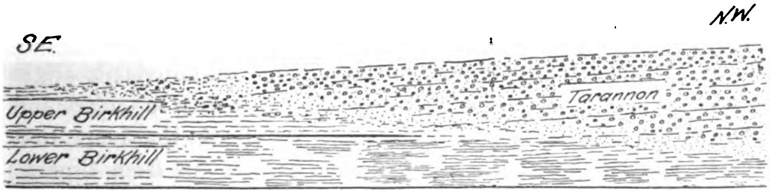

FIG. 11. IDEAL SECTION SHOWING RESTORATION OF CONDITIONS DURING LLANDOVERY-TARANNON TIME IN SOUTH SCOTLAND

It is readily seen that a startling conclusion must be drawn from the data, namely, that the Llandovery is not a time period separate from the Tarannon, but that the two are synchronous, the Llandovery being equal in age to the lower Tarannon and appearing as a wedge which widens southward till it reaches its maximum thickness of 96 feet in the Moffat region. The Llandovery is a black mud facies containing a mixed Ordovicic and Siluric fauna, the evidences of the presence of the latter being indicated by the numerous species of Monograptus, the Ordovicic aspect being supplied by the Didymograptus species.

The terrestrial origin of the Tarannon has been shown by two different and mutually independent lines of evidence. It is of interest, then, to find in the Upper Tarannon the fragment of a eurypterid. Near the southern border of the Central Belt just south of Bowden which is northeast of Selkirk, there is recorded the occurrence, in the grey blue shales and flagstones probably of the Hawick series, of the telson of Eurypterus and a fragment of Dictyocaris associated with crinoid stems. The typical Hawick rocks found in the neighborhood of Selkirk and further south at Hawick are themselves barren of all fossils but trails, burrows, and tracks. Near Selkirk Crossopodia and Myrionites have been found, while at Hawick Protovirgularia, Crossopodia, Menertites, Nereites and other tracks are abundant and the body segments of a Ceratiocaris have been found. The occurrence of the single eurypterid fragment in this great barren series is difficult to explain as a marine organism. It may be argued that the presence of crinoid stems is clear enough evidence of the marine nature of the deposits, but such disjointed stems might be washed out from an earlier deposit or even if of the same age as the eurypterid it is well known that those joints are swept great distances from the original habitat of the crinoids, and that they might be washed far inland on low-lying flats along the shore. At any rate, the single eurypterid remain fails to prove anything definite; it might be washed in from the sea, but then one must ask why the eurypterids are not found in the Tarannon muds in the regions where abundant graptolite faunas have been found. The fluviatile origin of the Tarannon has been amply shown, and it is easy to understand on the supposition that the eurypterids were living in the rivers, that fragments of the exoskeletons should be washed out from time to time. It may here be suggested that a further careful search in the Tarannon rocks might well yield a eurypterid fauna as fine and as unexpected as the fauna in the Shawangunk conglomerate. It is also not improbable that some of the tracks reported from the Hawick rocks were made by eurypterids, an interpretation in keeping with Patten's suggestion for the origin of Climatichnites (Patten, 206).

Following the retreatal phase of the Llandovery and the succeeding terrestrial phase of the Tarannon are the Wenlock beds. Though now exposed only in the southern belt below the tableland, in the small inliers in the Pentland Hills and Lanarkshire, and in the Girvan area, there is little doubt that the Wenlock at the time of its deposition extended entirely across this area. Such being the case, it represents the deposits of the advancing Wenlock sea. Continuous sections from the Tarannon into the Wenlock at various places in the belt south of the tableland show that the succession is conformable, thus proving that the line marking the end of the retreat of the sea must be northwest of this band and would lie, therefore, in the region of the tableland from which all Wenlock strata have, unfortunately, been removed. It is probable that the Tarannon-Wenlock shoreline was in the central or southern portion of the central belt. One of the finest exposures of the conformable contact of the Wenlock on the Tarannon is at Burrow Head, the outermost extremity of land between Luce and Wigtown bays just north of Solway Firth. The nature of the sediments along the belt south of the tableland indicates that oscillatory conditions prevailed, the seafloor being covered at times with fine muds, at others by coarse conglomerates. One would have expected that terrigenous deposits would have played a less important part there than in the Pentland Hills which are known to have been nearer the old shoreline. It is not unlikely that the land may have projected southward in a peninsula which lay between the present sites of Lanarkshire and Girvan, thus bringing the terrigenous sediments further south. In the southern belt there has been recorded a single occurrence of a eurypterid remain, so incomplete and so poorly preserved that it is specifically unidentifiable. Four miles south of Hawick at the junction of a small tributary with the Slitrig water Eurypterus sp. is reported associated with *Ceratiocaris papilio* and a number of graptolites. This type of occurrence, namely of a single eurypterid fragment associated with well-preserved abundant remains of marine organisms, has already been mentioned several times, and its significance pointed out. A general summary will be found below on page 194, in which the argument for the marine habitat of the eurypterids based upon such evidence is dealt with and, I trust, demolished for all time.

From the point of view of the determination of the habitat, we come now to the most significant occurrence of eurypterids thus far known in the British Isles. To be sure the "seraphims" of the Old Red Sandstone discovered by the stone-cutter of Cromarty and proclaimed by Agassiz to be "the remains of a huge lobster," are deservedly famous. Their size, abundance, association with the monster cephalaspid fishes, and above all the mystery attending their place in nature have shed upon the eurypterids of the Old Red Sandstone a picturesque and historical glow which makes the later discoveries of faunas merely so many cold triumphs of science. But the light which the Devonic merostomes throw upon the solution of the problem of the habitat cannot compare with that which emanates from the fauna of the Wenlock. And the reason is this: A large number of geologists have already come to the conclusion that the Old Red Sandstone was a series of torrential and flood plain deposits, in which case they can hardly fail to believe that the organisms found in the deposits were river-dwellers. Furthermore, it will not be a very difficult undertaking to convert the unbelievers in the river origin of the Old Red to staunch advocates of it. In fact, we may say that the case is so clear not only as to the lithogenesis of the deposits of the Old Red Sandstone, but also as to the medium in which the organisms of that time must have lived, that a few years' from now there will probably not be any thoughtful geologist who will not agree that the Devonic rivers supplied the sediments and were also the home of the Old Red fishes and merostomes. But in the case of the Wenlock it seems the rankest heresy to say that any of the organisms whose remains are found therein could be other than dwellers in the sea. The majority of palaeontologists would describe the Wenlock as exposed in the inliers north of the tableland in some such manner, "The Wenlock consists of a series of conglomerates, mudstones and grits with intercalated shale bands which are usually highly fossiliferous. While the coral fauna so characteristic of the Wenlock of England is lacking, there abounds, nevertheless, a representative marine assemblage which includes graptolites, brachiopods, pelecypods, gastropods, cephalopods, crustacea, and eurypterids. The merostome fauna is one of the largest known from a single horizon, comprising sixteen species, distributed in five genera, while the remains are so abundant that certain layers are almost like coal beds, they are so charged with carbon." Who, indeed, would have the temerity to claim that such a fauna of eurypterids with such associates could lead to any other conclusion but that the eurypterids dwelt in the Wenlock sea? It is just because such a conclusion in reality is entirely unjustifiable that I was led to state at the beginning of this paragraph that the eurypterid occurrence in the Wenlock is the most significant one in the British Isles when its interpretational value is taken into account.

WENLOCK OF THE PENTLAND HILLS. The Pentland Hills are formed from a series of the folded pre-Devonic beds and are completely surrounded by the various sub-divisions of the Old Red sandstone and by the igneous rocks. The Siluric rocks are exposed in four small isolated patches in these hills, and yet in spite of the small size of the outcrops and their isolation they have yielded more species of eurypterids than any other single formation in the world, with the exception of the Bertie waterlime, though there is this marked difference between the two faunas: whereas the Bertie fauna contains the most perfectly preserved individuals that have yet been recorded from any locality, with the exception of those from Oesel, the Pentland Hills fauna, on the other hand, is made up, for the most part, of fragmentary individuals.

The most important of these four inliers is that extending from the head of Lyne water to the head of North Esk River, a distance of about three miles. Although this inlier is the largest of the four it covers an area of only about two to three square miles. A number of excellent sections have been opened up by the North Esk and its various tributaries. The river itself cuts across the outcrop nearly at right angles, and since the beds here as in the other inliers are strongly folded, standing on end with the strike northeast-southwest, a considerable range in age is shown in the section, the lower beds appearing to the east, in the North Esk section where the Wenlock, Ludlow and a portion of the Lanarkian (Downtonian) are exposed, while to the west the Lyne water cuts through the passage beds or Downtonian. Of the numerous sections thus exposed the one which has now become most famous on account of the large eurypterid fauna discovered there by Hardie and Malcolm Laurie is that on the Gutterford Burn, a small tributary of the North Esk. (See map, fig. 12.) On the east bank of the burn, about a half a mile up from the North Esk Reservoir the strata consist of "flaggy micaceous greywackes" dipping at about 80 degrees to the southeast. Peach and Horne give a list of the fossils which they state come "from this band" (**215**, 593), but one may question the accuracy of this statement when com-

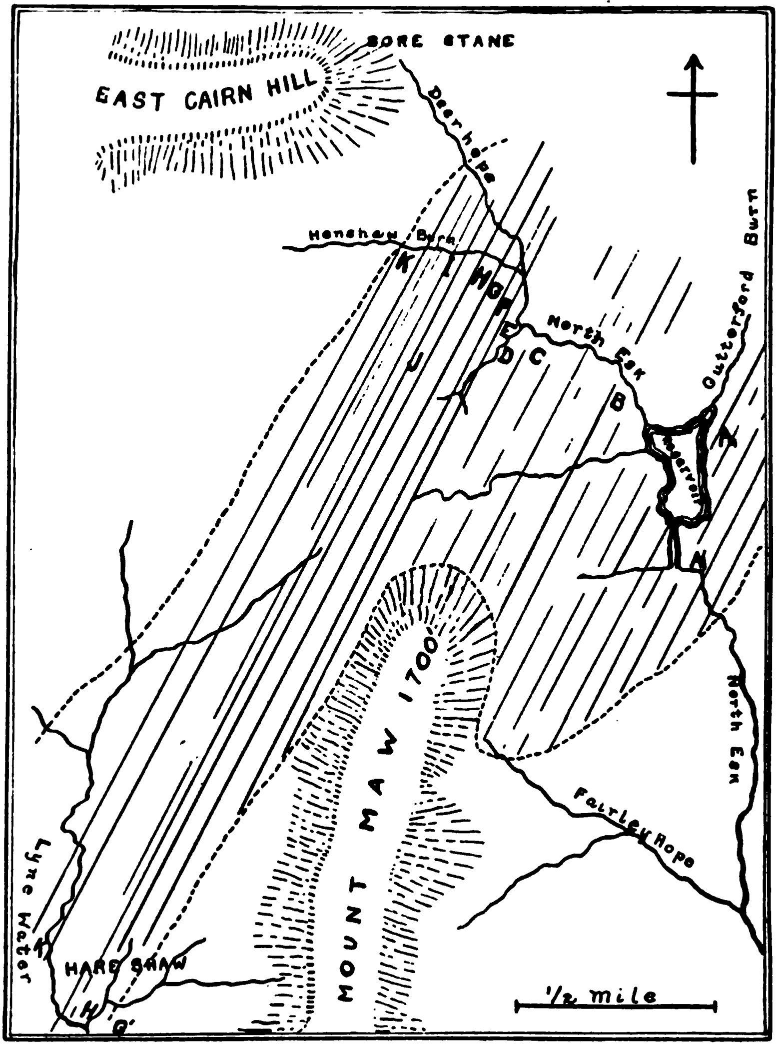

FIG. 12. SKETCH MAP GIVING OUTCROPS OF THE WENLOCK OF THE PENTLAND HILLS, SCOTLAND
(After Henderson and Brown)

pared with that made by Laurie at the time when he described the eurypterid fauna from these beds. He says: "The rock in which the Eurypterids are preserved is an irregularly fissile fine-grained sandstone, containing a considerable amount of carbonaceous matter distributed in thin layers. The only other recognizable fossil which occurs in the rock is the so-called *Dictyocaris ramsayi*, which occurs in considerable abundance" (**145**, 151). If one searches in the literature back to the time when eurypterid remains were first found in the Pentland Hills, one comes upon a description which is in but poor accord with the most recent one, emanating from the Scottish Survey, although bearing out quite well the statement made by Laurie. John Henderson in 1880 read a short account before the Geological Society of Edinburgh of some fossils which he had discovered in the Pentland Hills, in the beds in the Gutterford Burn. A few extracts from his paper will serve to give the clearest description which I have yet found of the eurypterid-bearing band. "This bed, which is upwards of a foot in thickness, is mostly made up of what I consider to be a mass of vegetable matter, along with an organism which has been described and figured by Mr. Salter . . . . as a large phyllopod crustacean under the name of *Dictyocaris ramsayi* . . . . there is in this bed a large amount of vegetable matter, some of the plant remains showing about one-tenth of an inch of carbon on the surface, and these plant remains are so associated with the supposed crustacean remains that it is difficult to determine the one from the other. I am now inclined to believe that the Dictyocaris is of vegetable origin. The fact of finding plant remains in such abundance in the Silurian rocks is, as far as I am aware, a new feature, as until lately true plant remains in that formation were considered doubtful. But there can be no mistaking their character and abundance in this bed, which is so thickly charged with carbon that it looks like an impure bed of coal . . . . the remains of undoubtful crustaceans of the genera Eurypterus and Stylonurus in a fair state of preservation occur in the same bed with the Dictyocaris and plant remains . . . . the bed in which these specimens are got must be at least as low as the Wenlock Shale. It lies several hundred feet below the fossiliferous bed in the North Esk above the reservoir, which is of undoubted Wenlock age" (**115**).

We do not know precisely the exact relation between the eurypterid-bearing bands and the beds containing the other fossils, but all available evidence indicates that they are not identical. Considering the decidedly different facies associated with the eurypterids and with the remaining fossils it seems probable that the former are confined to certain bands or lenses, as is often stated. In any case their occurrence is still capable of easy explanation whether they are actually in the same beds and really closely associated or whether they are found only along certain partings as is indeed indicated by Peach and Horne who say that "A characteristic feature of this eurypterid bed is the abundance on the divisional planes of that enigmatical fossil *Dictyocaris ramsayi*, forming, indeed, large black patches about an inch and a half across." One fact at least is clear: The eurypterids occur in a very thin band and are found in abundance in one section only, while a few fragments are found in one or two other nearby localities. The eurypterids are confined within a few inches vertically, while laterally the remains have a very limited extent, disappearing within a few yards. The occurrence at Gutterford Burn is in bed A of Brown and Henderson which contains ten species. Two species have been recorded from bed H to the northwest in a section exposed by the Henshaw Burn, a tributary of the North Esk. Except for these two isolated occurrences no eurypterids are found in the other beds or even in the same beds as they are traced along the strike. The remains of sixteen species representing five genera appear suddenly in a band a few inches thick, without forerunners in the underlying beds and with not a single straggler in the immediately overlying beds.

The following species of merostomes have been obtained from Gutterford Burn according to the identifications made by Malcolm Laurie (Peach and Horne, **215**, 132, 593, 594):

Bembicosoma pomphicus Laurie
Stylonurus (Drepanopterus) pentlandicus (Laurie) emend. Clarke and R.
S. (Drepanopterus) bembicoides (Laurie) emend. Clarke and Ruedemann
S. (Drepanopterus) lobatus (Laurie) emend. Clarke and Ruedemann
Eurypterus conicus Laurie
E. minor Laurie
Eusarcus scoticus (Laurie) emend. Clarke and Ruedemann
Eurypterus 3 sp. undet.
Stylonurus elegans Laurie
S. macrophthalmus Laurie
S. ornatus Laurie
Slimonia dubia Laurie
Dictyocaris ramsayi Salt
Palaeophonus loudonensis Laurie

In beds of the same series in this section the following marine organisms have been obtained, according to Peach and Horne:

Amphispongia sp.
Nidulites favus Salt.
Dictyonema venustum Lapw.
Dictyonema (Chondrites) verisimile Salt.
Cyrtograptus murchisoni ? Carr.
Monograptus priodon Bronn.
Monograptus vomerinus Nich.
Favosites sp.
Tentaculites tenuis Sow.
Palasterina sp.
Crinoid fragments.
Lingula lewisi Sow.
Lingula symondsi Salt.
Strophomena walmstedti Lindst.
Euomphalus rugosus Sow.
Conularia monile Lindst.
Conularia sowerbyi Def.
Conularia sp.
Orthoceras angulatum Wahl.
Gomphoceras ellipticum ? M'Coy

The form described as *Bembicosoma pomphicus* is somewhat problematical and may be more nearly related to Hemiaspis than to the eurypterids. Of special interest is the finding of a scorpion in these beds. There is only one specimen of *Palaeophonus loudenensis* and this is in a bad state of preservation so that it is impossible to tell whether this early scorpion was aquatic and gill-bearing, or terrestrial. Drepanopterus is a new genus founded by Laurie for the three species: *pentlandicus*, *bembicoides*, and *lobatus*, but they are all described from imperfect material; the first from a fairly good specimen, the other two from a few slightly better.[7] Laurie's genus Bembicosoma[8] with the one species pomphicus was established for a few rather good fragments, which, however, were only doubtfully identified. *Slimonia dubia*, also described by Laurie, is but poorly represented, as are likewise the three species of Stylonurus: *elegans*, *ornatus* and

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[7] Clarke and Ruedemann have placed Drepanopterus as a subgenus of Stylonurus.

[8] Laurie originally spelt the name Bembycosoma and the species of Drepanopterus, bembycoides, but in the corrigenda to his 1900 paper, p. 590, (147) he called attention to the proper form Bembicosoma and bembicoides, a change which has not been noted by later authors.

macrophthalmus. Imperfect remains are all that have been found of the five species of Eurypterus: *scoticus*, *punctatus*, *minor*, *cycloptkalmus* and *conicus.*

In the Girvan area near Straiton where continuous marine, though near-shore deposition was going on through Tarannon on into Wenlock time, the strata are found to be highly fossiliferous at certain horizons and graptolite bands are well made out. Collections made in a quarry near Blair Farmhouse not far from the village of Straiton have yielded a number of fossils, among which is a Eurypterus sp. Owing to the fact that British geologists seldom state the exact horizon at which fossils are collected, and of course this is often difficult to do when the strata stand on end and break off in slabs from which collections are made, it is impossible to say whether the eurypterid occurred in a seam with the crustacea while the undoubted marine forms occurred in other seams, as is found so often to be the case. The list given by Peach and Horne is merely quoted as coming from this quarry (**215,** 549).

Eurypterus sp.
Beyrichia kloedeni (M'Coy)
B. impendens (Jones)
Entomis globulosa (Jones)
Monograptus galaensis (Lapw.)
M. priodon (Bronn)
M. riccartonensis (Lapw.)
M. vomerinus (Nich.)
M. sp.
Retiolites geinitzianus (Barr.)
Favosites sp.
Lingula symondsi (Salt)
L. sp.
Orthis sp.
Siphonotreta anglica (Morris)
Cardiola fibrosa (Sow.)
Bellerophon sp.
Orthoceras subundulatum (Portl.)

After this rather careful study of the occurrences in the Wenlock, we are in a position to form a valuation of the hypothetical description of this formation and its fauna, which I gave on page 130 above, and which may be fairly taken as the prevalent view expressed in textbooks and by authors generally. The main statement that is dwelt upon insistently, and which is so dangerously plausible, is that in the Wenlock the eurypterids are found in an undoubted marine formation in association with typical marine fossils. Such a statement is full not of truths, but of half truths, and these are far harder to combat than actual untruths. In the present instance we have only to consider how much weight would attach to such a statement if the following significant bits of information were added: (1) The eurypterids do not occur in the same beds with the undoubted marine forms, but always in certain leaf-thin bands which carry no other fossils except *Dictyocaris ramsayi*, a form which may be a fluviatile if not a terrestrial plant or animal, but the systematic position of which is at present wholly undetermined. The thickness of all the beds containing the eurypterid-bearing bands is only one foot; it is a grit and greywacke; the typical marine fossils are found in the shales and in limestone lenses. (2) Not a single complete eurypterid has been found among the hundreds of specimens collected and the very species described by Laurie have usually been founded upon fragments. (3) The exoskeletons have not only been dismembered—this might be expected in any case, for during the process of decay the various members might fall apart and thus be embedded in the mud, few complete individuals being entombed—but the fragments are macerated, the edges are broken and worn, the surface sculpturing indistinct, altogether showing evident signs of wear. (4) The occurrences are not widespread; although many good sections are obtainable in the Pentland Hills inlier, in only two places are eurypterids found. In both cases the remains are confined to bands a few inches thick, extending laterally but a few feet. (5) The eurypterid fauna appears suddenly with no forerunners and no descendants so far as may be judged from the faunas of the beds immediately below and above the bands containing eurypterids; two of the five genera are confined to this horizon. (The full significance of statements (4) and (5) will be taken up in the next chapter on distribution.)

These are the facts which are generally not mentioned when the eurypterids are declared to be abundantly represented and associated with a good marine fauna. These five facts seem to be difficult of explanation if it be supposed that the eurypterids were marine organisms. How are we to account for the fact that the merostomes accompanied by that form which so often occurs with them, *Dictyocaris ramsayi*, are found in layers separated from those containing the brachiopods, pelecypods, etc.? If the eurypterids lived in the marine waters, why are their remains not found with those of the other marine organisms? Band D contains many genera, species, and individuals of brachiopods, pelecypods, gastropods, cephalopods, crustacea, crinoids, trilobites, corals, the first three groups being especially well represented, the last three by only two or three species. But not a trace of a eurypterid is found in this fauna which, according to the criteria given on p. 76 is a typical marine fauna. Moreover, why should their appearance be so sudden and so localized? The eurypterid band dies out within a few yards of Gutterford Burn, and in the other sections where one would expect to find eurypterids again, for the associated marine fossils occur, there is not even a fragment? I must confess that such anomalies in distribution are not compatible with a marine habitat for the organisms so affected. Again, why should the eurypterids have suffered such maceration, while the remains of the other organisms were entombed in a perfect state? Wonderfully preserved starfishes and trilobites are found in one of the beds, the marvellous brachiopod fauna of Band D has been described and figured by Davidson, and his book amply attests to the abundance and fine preservation of the molluscoidea; but the eurypterids are broken up, often unidentifiable and never what the palaeontologist would consider good material. These questions have been, or will be, fully treated in the appropriate sections on the bionomy and distribution of the eurypterid faunas. We are here concerned only with the lithogenesis of the beds so far as that may be separated from faunal considerations. From the study of the sections, and the lithological characters of the rocks, I offer the following interpretation for the eurypterid-bearing horizons of the Wenlock of southern Scotland.

It will be remembered that the Tarannon marked a period of retreat of the sea toward the south, the shoreline being at the end of that time somewhere in the central part of the Central Belt, while there must have been an embayment in the Girvan area where continuous marine sedimentation was active. The Wenlock sea which covered the greater part of western, central, and northern England at least, advanced over the terrestrial beds which were deposited during Tarannon time. Unfortunately, the most critical areas of deposition of the Wenlock have been removed by subsequent erosion. The Southern Belt was in the region of continuous marine deposition from Tarannon into Wenlock time, as the sections in many places show. Even in the Pentland Hills the base of the Wenlock is nowhere visible, the beds standing on end for the most part and sticking up through the Old Red Sandstone. In Lanarkshire, however, there occurs in the Lesmaghagow inlier only, below the Ludlow, a series of blue greywackes with shale partings which is 1300 feet thick and has proved unfossiliferous throughout except in one locality where a few specimens of Murchisonia (specifically undeterminable) and some doubtful forms called Orthis have been found. It has been thought by the Scottish Survey that part at least of this formation was Wenlock in age. I should like to offer the following purely theoretical suggestion. It has been shown that during Tarannon time rivers flowing from the Eastern Highlands carried down pebbles and boulders which were deposited in the Central Belt. Probably the whole of central and northern Scotland was above water then, and either subaerial erosion or deposition was going on. The 1300 feet of greywackes and shales below the Ludlow in Lanarkshire might represent in their lower part delta or torrential deposits accumulated during Tarannon time and in their later part similar deposits during Wenlock time. Their unfossiliferous character and great thickness would thus be accounted for. Future study in those rocks should be directed towards the search for cross-bedding, if any, and the type represented, for plant remains, tracks, and eurypterids. As the Wenlock sea advanced northwards—there is little reason to doubt that it did, for the same marine fossils are found in the Southern Belt and in the Pentland Hills—it reworked the Tarannon, and a basal sandstone, conglomerate or shale was formed, depending upon the nature of the Tarannon continent where the sea transgressed. Thus along the northern border of the Southern Belt the basal Wenlock consists of "greenish grey, flaggy grits, separated by grey shale bands, some of which are crowded with Crossopodia, Nemertites, and other tracks, resembling those found in the Hawick Rocks." On the Slitrig Water the shales and surfaces of the greywackes are crowded with tracks. These rocks pass conformably downwards into the Tarannon rocks of Hawick, indicating that the actual seashore at the close of Tarannon and beginning of Wenlock time must have been just about in this region. The unfossiliferous grits and greywackes (the first division of the Wenlock) appear along the northern border, while the second division occupies all of the rest of the belt to the south except for small patches or inliers in the extreme south where the third division of the Wenlock is seen; there are also inliers in various localities throughout the belt east of Langholm, showing the basal grits and greywackes projecting up through the second division of the Wenlock. This distribution indicates the presence of the basal sandstone of the advancing sea throughout the southern belt. The single eurypterid fragment found in this belt, it will be recalled, was discovered in the track-crowded shales and greywackes at Slitrig Water. These being interpreted as basal beds of an advancing sea, it is most natural to expect that the sea, rolling landwards and up the rivers, slowly but unceasingly converting the dry land into sea-floor, should catch river-dwellers who were not able to or did not migrate upstream fast enough, and even if there were none such, at least dead remains would inevitably be passed over by the sea in its continued advance. One would undoubtedly expect more than a single fragment and probably more will be found in the southern Wenlock rocks. The more abundant occurrence in the Pentland Hills is explainable on the supposition that the sandy bands containing the broken exoskeletons represent the outwash from rivers into the sea, of shed exoskeletons and maybe even of the remains of eurypterids which were killed off in great numbers by the entrance of salt water into the rivers. So soon as this group of organisms was able to migrate far enough away from the sea which had overtaken the earlier individuals, the appearance of exoskeletons in that region would come to an end, but one would expect similar catastrophes to occur in another locality at a higher horizon. Unfortunately, the exact method of entombment must remain hypothetical, since the exposures are so few, but that the eurypterids did not live in the Wenlock sea is apparent. One further argument which might be adduced is that in the purely marine, open-sea Wenlock of England, not a trace of a eurypterid has been found, although if they were true marine organisms during Lower Siluric time as most geologists claim, then it is surprising that they alone of the marine fauna should be found only in southern Scotland although migration was open along most convenient marine channels into Wales.

8. UPPER SILURIC OF OESEL

For beauty and perfection of preservation no other known eurypterid remains can compare with those from the island of Oesel. Though only five species have been found and only one in abundance, the lack of a varied fauna is entirely compensated for by the rare condition of the fossils. After tens of millions of years the exoskeletons of these organisms now so long extinct appear in the rock, differing not in appearance from the shed skin of a Limulus buried in the sand today. We must be filled with awe and with the profoundest admiration for the marvellous ways of nature, when we look upon these remains unchanged in chemical or physical characters during all the aeons which have passed since they were entombed, still retaining the brown color so familiar in modern horseshoe crabs, with the very chitin of the test unimpaired, while even the brittle exoskeleton itself, at times, can be removed from the rock intact.

FIG. 13. SKETCH MAP OF OESEL FOR UPPER SILURIC LOCALITIES

HISTORY OF DISCOVERIES. This fauna was discovered in 1852 by Dr. Alexander Schrenk, during a trip made for the purpose of studying the Ordovicic and Siluric rocks of the northwest provinces of Russia, namely, Livland and Estland, and of the adjoining islands Oesel, Dago, Moon, Worms, etc. On the first and largest of these islands he found outcrops of the uppermost Siluric rocks in the town of Rootziküll (see map, fig. 13) and there he came upon the first of the eurypterid fauna which was to become world renowned.[9] In his report on this region he says: "The gray, compact dolomite of Rootziküll, on the west coast of Oesel, reveals the thin membraneous tests of *Eurypterus remipes* Dekay [= *E. fischeri* Eichwald] entirely unchanged, not only in their chemical composition, as pure chitin, like that found in the shells of living Crustacea, but also in their whole internal microscopic structure and preserved with their original brown color peculiar to living animals" (Schrenk, **254**, 35).

In the following year, 1853, Eichwald apparently not knowing of Schrenk's discoveries visited the same provinces and islands and on Oesel two versts from Rootziküll in the village of Wita he, too, came upon the eurypterid horizon whose assemblage of organisms surprised him not a little, for he says: "I was astonished to find a vast multitude of *Eurypterus remipes* [*E. fischeri* (Eichwald)] in this limestone" (Eichwald, **57**, 49). By his collections he added much to the knowledge of the rest of the fauna, but I shall not at this point give the species which he found, since later workers added materially to the faunal lists. During that same summer Schmidt and Harder accompanied Eichwald to Wita and other nearby localities where eurypterids were found; in 1856 Schmidt returned again to Oesel and the following year Niezkowski, Schmidt and Czekanowski made large collections at the best localities. Again in 1858 Schmidt revisited the island, and as the result of these extensive collections and field studies several important papers were brought out. By far the most complete and comprehensive were those by Schmidt, the first published in 1858 entitled "Untersuchungen ueber die Silurische Formation von Ehstland, Nord-Livland, and Oesel"[10] embodies the first detailed stratigraphic and palaeontologic discussion of these regions. Schmidt gave the first geologic map of the region and the zonal subdivision of the "Silurian" which is still used in the east Baltic provinces. In the following year Schmidt published a short notice on some further discoveries in Oesel (**243**). His most important paper on this island appeared a number of years later in 1883 as one of the "Miscellania Silurica" in the Memoires de l'Academie Imperiale des Sciences de Saint-Petersbourg, entitled "Die Crustaceenfauna der Eurypteren-

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[9] He had been led to look for this fauna because he had noticed in the Dorpat Museum certain fine specimens which had been sent in from Arensburg, southeast Oesel, by Oberlehrer Werner, who had knocked them out of loose blocks of building stone. (Nieszkowski, 197, p. 303.)

[10] It is true that pioneer work on the mainland had been done by M. v. Engelhardt and E. Ulprecht. the results being embodied in a paper entitled "Umrisz der Felsstructur Ehstlands und Livlands" in Karsten's *Archiv für Min. Geogn. Bergbau u. Hüttenk.* for 1830, but the paper does not touch on Oesel. Similarly in the Geology of Russia by Murchison, de Verneuil and Keyserling Oesel is passed over in a few sentences.

schichten von Rootziküll auf Oesel." Precise information is given regarding localities, species are fully described and compared with related forms and excellent illustrations are given, so that with these papers and one by Nieszkowski in 1859 on "Der *Eurypterus remipes* aus den obersilurischen Schichten der Insel Oesel" (197) one may gain an accurate knowledge of the fauna and the sediments. Notes by Nieszkowski in connection with his work on the trilobites have proved helpful, and for further details the reader is referred to the titles under his name in the bibliography as well as to numerous papers by Schmidt.

GENERAL STRATIGRAPHY. The Siluric exposures on the island of Oesel include two divisions: the lower Oesel group or zone I, and the upper Oesel group or zone K of Schmidt. The strata have a gentle dip to the south so that higher and higher beds appear in that direction. The lower beds, of Wenlock age, cover a considerable part of the northern half of the island, while the upper or Ludlow beds are found in the southern portion (see map, fig. 13). In the extreme north the lowest part of zone I occurs carrying typical Wenlock fossils; southward, as on the peninsula of Taggamois the upper division of the zone is exposed, showing well its dolomitic reef structure; bryozoa, crinoids and brachiopods are abundant, and do not differ essentially from the forms in the underlying marls. The last exposures of the upper part of zone I yield abundant *Thecia swindernana*, a coral found in the Upper Visby beds of Gotland, also *Leperditia baltica*, which occurs in divisions V, VI and VII of North Gotland, *Strophomena imbrex*, found throughout the Wenlock or lower divisions in Gotland, and *Zaphrentis conulus*, characteristic of the upper part of the Visby formation (III) immediately below the Pterygotus marl of Gotland. This higher portion of zone I is to be correlated with the *Leperditia baltica* zone of Gotland (Schmidt, 250, 132).

Throughout the entire south and southwestern parts of the island, zone I is succeeded by zone K, but the actual contact is nowhere observable. This zone likewise shows two subdivisions, a lower, made up of thin-bedded "plattenkalk" or dolomite, in some places unfossiliferous, in others carrying eurypterids and fishes, and an upper very fossiliferous horizon known as the Ilionia beds on account of the abundance of that pelecypod. The Ilionia beds are to be correlated with zone VI of Gotland which is of Upper Ludlow age. Some of the diagnostic Upper Ludlow fossils recorded from this horizon in Oesel are: *Ilionia prisca*, *Megalomus gotlandicus*, which occurs just above the Ilionia beds in Gotland, *Murchisonia compressa* (Gotland VI), and *Spirigera* (= *Meristina*) *didyma*, which is the most widespread form in the northern outcrops of zone K in Oesel and which occurs at Visby in the top of bed III, in the Sphærocodium marl below the Ilionia limestone, and above the eurypterid marl of Gotland, as well as in the Aymestry limestone and Dayia beds of England, all (except possibly the last two) of Upper Ludlow age. Thus there is evidence of a faunal break in the series, since beds containing Upper Ludlow fossils everywhere in eastwest sections across central Oesel follow upon beds with Wenlock fossils. In many localities the indications of a physical break are also present as may be best shown in a few detailed sections.

The fullest development of the eurypterid fauna is seen in the rocks underlying Rootziküll on the west coast of the island of Oesel in the parish of Kielkond. Here the beds of the lower part of zone K are a fine-grained "plattenkalk" or dolomitic calcilutyte, in which the chitinous exoskeletons of *Eurypterus fischeri* Eichwald, *E. laticeps* Schmidt and *Pterygotus osiliensis* Schmidt have been so excellently preserved. Associated with the eurypterids in the same bed have been found the tail of *Ceratiocaris nötlingi* Schmidt,[11] the shields of two cephalaspid fishes *Thyestes verrucosus* Eichw. and *Tremataspis schrenkii* Schmidt, and the shells of the little *Lingula nana* Eichwald. Nearly fifty years after these first discoveries Schmidt was able to add a new species to the fauna perhaps representing a genus not heretofore known outside of North America. From A. Simonson he obtained a slab which showed the portion of the abdomen and carapace of this new species which he called *Stylonurus* (?) *simonsoni* (252, 157).

Attention has already been called to the fact that the eurypterid exoskeletons have the original chitin still preserved and that this may be lifted from the rock so that both the upper and under surface and the sculpture thereon may be studied. The shells of the remaining fossils which are found in this bed are destroyed; these include the rarely occurring Hemiaspids: *Bunodes lunula* Eichw., *B. rugosus* Nieszk. and *B. schrenckii* Nieszk sp. as well as *Pseudoniscus aculeatus* Nieszk. and the shells of *Orthoceras tenue* Eichw. All of these forms are represented only by carbonaceous films. In the environs of Rootziküll the eurypterid-bearing plattenkalk appears at the surface

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[11] This species was not collected by Schmidt but was described by him from a specimen from Volborth's collections.

everywhere and as Schmidt puts it, "In the extent of a single ½ verst one may here lay out places for eurypterid quarries to one's heart content" (**248**, 29).

Above the plattenkalk horizon is a brecciated limestone of no great thickness consisting of angular or slightly rounded fragments of compact limestone in a matrix of similar limestone which contains *Calamopora polymorpha*. The breccia is not derived from the underlying dolomite, according to Schrenk (**254**, 47). This physical evidence of a break at the top of the eurypterid dolomite has been more fully described from other localities, as, for instance, at Wita, the section next to be considered.

To the southwest of Rootziküll is the village of Wita. Here in the yellowish white dolomite which is the characteristic eurypterid-bearing facies two quarries have been opened. It was found that the eurypterids occurred not only in the dolomite, but also at a higher horizon in a brecciated coral limestone which is made up of angular, sometimes rounded white nodular masses which are for the most part corals lying embedded in a uniform, yellow, marly limestone matrix. Schmidt (**241**, 167, 168) would correlate this bed with the Burgsvick oölite of Gotland, the formation which there marks the break between the upper and lower Gotlandian. The limestone at Wita is only one foot thick; in its upper part it contains *Leperditia baltica*, *Turritella obsoleta* (= *Holopella obsoleta*), *Spirifer elevatus*, and certain corals, all being characteristic of the Upper Ludlow of England and of the Upper Gotlandian of Gotland. In the lower portion of the breccia occur: *Cephalaspis verrucosus*, *C. schrenkii*, *Eurypterus fischeri*, *Bunodes lunula*, a new crustacean *Dithyrocaris* ? sp., *Orthoceras bullatum* ?, *Lingula nana*, and *Palæophycus acicula*, besides many fragments of crustacean claws, segments of walking legs and the like. The section is of importance for three reasons: (1) There is physical evidence of a break at the end of Wenlock or Lower Ludlow time, marking a retreat of the sea. It did not return until Upper Ludlow time as indicated by the presence of fossils of that age in the matrix of the brecciated limestone. (2) The eurypterids occur abundantly in the beds deposited immediately after the normal marine conditions ended, while the sea retreated, and at the time when dry land was being enlarged and consequently rivers were extending their distal portions. (3) The eurypterids are also sparingly found in the breccia and conglomerate which marks the return of the sea and renewed deposition of marine sediments with marine organic remains. (4)

The eurypterids do not occur in the beds with the marine fossils but always in distinct zones a few inches thick, their whole representation being confined to not more than a few feet in the entire Oesel series.

West of Rootziküll a distance of about 5 versts there is an exposure not far from Gesinde Wessiko Maddis along a little brook which rises near Lümmada, but is usually dried up. Here the lower rock is limey, not dolomitic and the eurypterids are not very abundant, but the rock above is crowded with *Platyschisma helicites*, *Leperditia phaseolus*, and the delicate fish scales of *Coelolepis schmidti* Pander together with fragments of seventeen other species of fishes (Schmidt, **241,** 168, **248,** 29). The upper beds are evidently the continuation of the brecciated limestone of Wita. Proceeding in the same southwesterly direction from Rootziküll towards the coast one comes to the Attel estates or Gut Attel where there is a small outcrop of yellow, coralline limestone which on exposure weathers white and which carries *Stromatopora* sp., *Cyathophyllum*, *Favosites hisingeri*, and *F. fibrosa;* similar brecciated inclusions occur as at Wita. A little farther to the west in the village of Attel may be seen on the west side of the deeply indented bay a coarsely crystalline yellow-dolomite and beneath this is the coral limestone of the Attel estates which here is not entirely composed of corals, but contains also *Eurypterus fischeri*, *Lepeditia baltica*, *Orthoceras bullatum*, and *Murchisonia cingulata* = *M. compressa*, the last being the same species which is found in zone VI in Gotland. It is clear that the eurypterid remains at Attel are found not in the plattenkalk beds, which here are barren of all organic remains, but in the overlying coral limestones (Nieszkowski, **197,** 307; Schmidt, **241,** 169, 170). The last section in this series is at the Soegi-ninna point about 12 versts from Rootziküll, where the rock walls rise from the sea to a height of 10 or 12 feet. In the upper part is seen the typical crystalline dolomite with nodular inclusions which here and there give place to thin, unaltered limestone beds with *Leperditia baltica* and *Murchisonia compressa;* the lower part of the rock walls consists of platten dolomites which appear to be the continuation of those of Wita, but which have not yet yielded any eurypterid remains after fifty years of patient search (Schmidt, **151,** 169, 170).

The outcrops in the southeastern portion of Oesel show only traces of eurypterids here and there. For instance, between Uddafer and Ladjal, north of Arensburg, Schmidt found in small ditches along the roadside *Phragmoceras* sp., *Spirigerina prunum*, *S. didyma*, *Pleuro-*

rhynchus sp., *Laceripora cribrosa*, but no eurypterids. In the quarry at Ladjal itself, in a band of limestone apparently in place, there occurred a great mass of *Leperditia baltica*, and also *Spirigerina didyma*, while in marly interbedded layers *Eurypterus fischeri* occurred in traces. To the southeast this limestone merges into solid gray limestones carrying trilobites, crinoids, brachiopods, etc., but not eurypterids. At Nessoma, southeast of Sandel occurs an outcrop of the upper crystalline limestones which marks the *Spirigerina prunum* horizon, and in intercalated brown marly layers were found great numbers of fish scales and breast plates, similar to those occurring at Ohhessare-Pank on the southwestern end of the island. The section at Lode about the same distance west of Arensburg as Nessoma is east of it, has brought to light one of the richest collecting grounds on the island for the typical marine forms. Here the rock is a gray limestone in which *Spirigerina prunum* occurs in great numbers but is not well preserved; *Leperditia baltica* is occasionally found, but the abundant forms are: *Calymene blumenbachii*, *Orthoceras bullatum*, *Spirifer elevatus*, *Orthis orbicularis* and *Chonetes striatella*, all characteristic of the Upper Ludlow of England (Schmidt, **241**, 176–7).

In summary, it may be said that the detailed sections bring out the sporadic occurrence of the eurypterids in very thin beds, rarely intimately associated with the typical marine forms which occur in beds above and below the eurypterid marls. As the beds are traced to the south, southwest and southeast they are seen to be replaced by those containing a pure and abundant marine fauna, but not a trace of a eurypterid. Moreover, it is apparent that the occurrences are in all cases immediately associated with the physical and faunal evidences of a break in the series between beds of Lower and Upper Ludlow age, and that this is essentially the horizon at which the eurypterids and *Palæophonus nuncius* are found on the island of Gotland, marking in both cases what seem to be widespread river deposits which precede the renewed encroachment of the sea in Upper Ludlow time.[12]

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[12] It does not appear to me necessary to take up in detail the discussion of the occurrence of the Pterygotus marl of Gotland, since the conditions there are identical with those of Oesel. The marl overlies beds with a Wenlock fauna, and is succeeded by beds with an Upper Ludlow fauna. The physical evidence of the break between the two series is marked throughout the island. This is fully discussed in a forthcoming paper by Professor Grabau.

9. UPPER SILURIC OF PODOLIA AND GALICIA

Along the Dniester and its tributaries in Galicia and Podolia Upper Siluric rocks have been found containing a few fragments of *Eurypterus fischeri*. This discovery was one of the earliest and was made by Major-Ingenieur Bloede who found a single impression in a piece of shale from an unknown locality in Podolia. Graf Fischer de Waldheim described this form as *Eurypterus tetragonophthalmus*, communicating his description to the Société Impériale des Naturalistes de Moscow in 1839 (**64**). The specific name was given because the eyes were supposed to be of a tetragonal outline, but subsequent study showed that they had the typical margins, and the form was later identified first as *E. remipes*, then as *E. fischeri*. Schmidt records finding the eurypterid remains at the base of the Upper Siluric and notes that just as in the occurrences on Oesel so in Podolia the eurypterids and fish remains are found without any other associates. In regard to the occurrence of *E. fischeri* noted by Barbôt, Malewski, Alth and others, Schmidt makes the following remarks: "In Podolia occurs a species absolutely identical with ours which was formerly identified with *E. remipes*, and which will probably make possible even further differentiation from the American species. So far as I know there have been but three undoubted specimens found up to this time: (1) the original specimen of Fischer (now in Moscow) from Zwilewcy on the Smotricz, (2) Bloede's specimen (in our Bergakademie Museum) from Balagowa on the Dniester, (according to Barbôt); and (3) that from the Kiew Museum obtained from Dumanow. Malewski also cited Zawalje, Kitaigorod and Studzienica; but I cannot hold these statements as very reliable, since the specimen from Studzienica which is before me, is the horizontal section of a large *Cornulites serpularius* (Sil. Syst.) which species is well known to me from Oesel (Johannis)" (Schmidt, **245**, 13, 14). The Pterygotus fragments which have been reported, Schmidt considers as identical with *P. osiliensis* (formerly called *P. anglicus*) from Rootziküll. Schmidt continues: "Of the latter I know practically every single piece, but I have never found a complete individual. Also in the transition beds from limestone to sandstone at Zalesczyki I have found broken pieces of shell, which, however, deserve no particular further examination (**245**, 13)." In another place, referring to this last mentioned occurrence he makes the following significant statement: "The uppermost beds at Zalesczyki become sandy and red and the fish alone are present besides the rare Pterygotus" (245, 9). (See sketch map, fig. 14.)

While Alth's paper is undoubtedly excellent for the general stratigraphy and palaeontology of Galicia and Podolia, involving as it does not only the results of his own studies but also those of the earlier investigators, it yet fails to give just the details which are essential for the problem in hand. It helps us very little to know that the eurypterids and a large number of the fossils are found in beds some 25–30 feet thick; the important fact is whether or not they occur in thin bands, isolated from the remaining fossils as is the usual way. It must in fairness be stated that Alth's section on the Upper Siluric beds, or as he called them, the "compact and bituminous limestones," does not pretend to be more than a résumé of the important but little known works by Barbôt, de Marny and Malewski, written in Russian, but now made available through this careful German summary. Schmidt's statement has shown that the mode of occurrence above

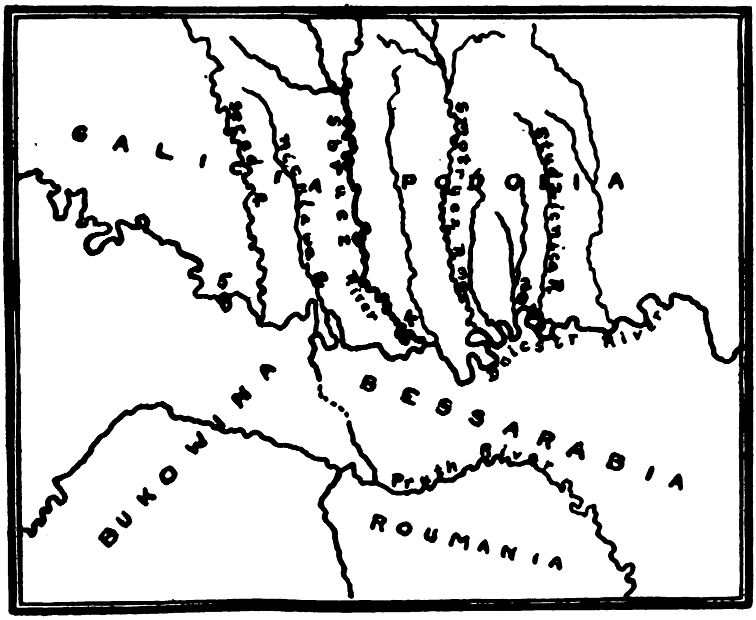

FIG. 14. SKETCH MAP OF PARTS OF GALICIA AND PODOLIA, SHOWING LOCALITIES WHERE EURYPTERIDS HAVE BEEN FOUND

1, Studzienica; 2, Kitaigorad; 3, Kameniec podolski; 4, Zawale; 5, Zalesczyki.

referred to as normal holds also in this case for Pterygotus, but there are many other occurrences for which no data are available. However, the rarity and the poorness of preservation of the fragments which have been found make it a matter of no great importance whether the eurypterids are intimately associated with the marine forms or not. I shall here list the localities as given by Alth and other workers in the same field.

Eurypterus fischeri. 1. Eichwald reports this in a black, compact limestone with corals from Kamieniec podolski, Podolia.

2. Malewski reports it from the same limestone at Dumanów, Zawale and Studzienica, Podolia (see Schmidt's remarks above, p. 148).

3. Fragments reported by Wenjukow from Dumanov, Podolia.

4. Siemiradzki reports this species from Zalucze on the Smotrycz river, in a yellow marly limestone (**263**, 215).

Pterygotus osiliensis. Exact locality and horizon not given for Alth's specimens.

Schmidt reports this species from transition beds of Zalesczyki, Galicia.

Siemiradzki has also recorded the finding of fragments which seem to be similar to Alth's undetermined Pterygotus sp. in the olive green shales from the same locality (**263**, 215).

Stylonurus sp. Alth. 1. A tail spine from the plattenkalk of the Borszczower beds from Zamuszyn (Alth Plate V, fig. 4).

2. A tail spine from the light greenish-gray marls into which the gray limestones of the Skalaer group pass upwards, found in the region of the Zbrucz Valley opposite to Zajączki and north of Husiatyn. (Alth Plate V, fig. 5).

3. A tail spine from the thin limestones opposite Zamuszyn (Alth Plate V, fig. 6).

These occurrences in Galicia and Podolia follow the general rule of being very fragmentary and isolated. From the literature one cannot tell whether the eurypterids were actually found in the same beds with the undoubted marine forms or not.

Pterygotus sp. ind. Siemiradzki. Siemiradzki has reported the occurrence of a telson of an undeterminable species of a Pterygotus from the Devonic coral limestone of Skala, Galicia (**263**, 215). This is mentioned here to complete the survey of the Austro-Russian occurrences.

THE LUDLOW OF ENGLAND AND THE LUDLOW AND LANARKIAN OF SCOTLAND

Introduction. Although the Siluric of southern Scotland is characterized by large eurypterid faunas at successive horizons, the rocks of the same age in England and Wales, where more open marine conditions obtained, have yielded only two or three fragments, except in the higher Ludlow beds which mark the transition to the continental deposition characterized by the Old Red Sandstone. Even in the Ludlow the remains which in some strata are abundant show a much poorer preservation than do those from Scotland. Complete individuals are never found and although it is possible from the fragments to determine that different genera are represented, more precise identifications are difficult, and in most cases species have been erected simply in order to have some way of designating the fragments belonging to the various genera. In order to understand why all of the specimens from the Siluric of England are so much more poorly preserved than are those from Scotland, it will be necessary briefly to trace the geological changes which were taking place throughout Great Britain during the later Siluric.

In Scotland the Upper Siluric is marked by the approaching continental conditions as evidenced in the deposits of greywackes and flagstones, some barren, some containing a sparse marine fauna and others only fish and eurypterid remains. The conditions as yet were unstable, showing the alternate dominance now of river-borne sediments and now of shore deposits. To the south, however, the sea still covered most of England, though the muds pouring in from the land had made conditions unfavorable for many of the forms of life which thrived in that region during Wenlock time. Thus the corals no longer built up great reefs and only a few survived in the stifling muds wherein the graptolites were buried in such abundance. Brachiopods and the majority of molluscs likewise decreased in number as the migration to more favorable waters to the south progressed. Toward the top of the Upper Ludlow rock in England many rill and ripple-marked sandstones are to be found, some of which show trails. Near the top of this series too, occurs the "Bone-bed" which varies from ¼ inch to 6 inches in thickness and is made up largely of fish, eurypterid and crustacean remains, while a few brachiopod shells have been found in places. Geikie has estimated that this bed probably covers an area of over a thousand square miles and yet it never exceeds and seldom reaches 1 foot in thickness.

Following the Upper Ludlow in England comes a series of formations of no very great thickness which has been subdivided into the Tilestones, Downton Castle sandstones, and Ledbury shales. Murchison applied the name "Tilestones" to the whole of the flaggy upper parts of the Ludlow, and since many of the beds are red he included them in the Old Red Sandstone. They were believed to mark a transition period between the Upper Siluric and the Lower Old Red, but to be more like the latter with which they were therefore classed. The Downton sandstones are a group of red, yellow and gray micaceous rocks from 80 to 100 feet thick, occurring in the neighborhood of Downton Castle, Herefordshire, and also supposed to mark a transition period. They are undoubtedly indicative of the regressive movement of the sea, which began in Lower Ludlow time in Scotland but which was not strongly felt in England till the end of the Upper Ludlow. Then in the Downtonian and other "passage beds" were washed into the deposits, terrestrial and lycopodious, vegetal remains, together with eurypterids, Ceratiocaris and vast numbers of *Beyrichia kloedeni*, together with *Lingula cornea* and *Platyschisma helicites*.

In Scotland all of the beds above the Upper Ludlow are called, by the Geological Survey of Great Britain, the "Downtonian." This series is to be looked upon as "stratigraphical equivalents of the Tilestones, Downton sandstones and Ledbury shales which, in Herefordshire, overlie the Upper Ludlow Rocks and have been classified as forming the highest subdivision of the Upper Silurian rocks" (**215**, 568). It is evident that such a usage of Downtonian will lead to endless confusion, for not a little misunderstanding has already arisen because some authors have placed the English Downton beds in the Lower Old Red, and others have used Downton and Passage Beds almost synonymously. If an attempt is made to use Downtonian in a comprehensive way, coördinate in importance with the terms Wenlock and Ludlow, then difficulties will arise and much circumlocution will be necessary to explain whether the Downton of England or the Downtonian of Scotland is meant and in correlation difficulties will come about because so many different deposits are known by the same name. And especially does it seem inadvisable to adopt a name which in England is used for a subdivision of the Ludlow, and make it in Scotland of the same rank as Ludlow. Therefore, the author most fully agrees with the suggestion made by Goodchild that all of the rocks above the Upper Ludlow in Scotland be hereafter designated by the term *Lanarkian* from the locality in which those higher Siluric beds are so well exposed.

The Lanarkian is a series of conglomerates and sandstones with a total thickness of about 2800 feet, which are either unfossiliferous or contain only fish and eurypterid remains with the usual ostracods, and with Dictyocaris and Ceratiocaris. Plant remains, a myriopod and a scorpion are among the local associates of the above fauna. The series in Scotland is a more strongly marked continental one than that in England. Thus there was a gradual retreat of the sea from the north towards the south, beginning in Scotland in Lower Ludlow time, if not earlier, and leaving all of England except Devonshire dry by the end of the Siluric.

THE UPPER SILURIC OF ENGLAND. It is only the higher divisions of the Ludlow in England which contain eurypterids: i. e., the Upper Ludlow rock, the Ledbury shales, the Downton Castle sandstone, and the Tilestones, according to the commonly accepted classification. Elles and Slater, who have done a great deal of work in the Ludlow district, have been able to determine smaller subdivisions; and since it is from these horizons that the eurypterids have been obtained, I quote so much of the new classification as is needed to follow the merostome occurrences (61, 198).

III. Temeside Group	F. Temeside or Eurypterid shales.
	E. Downton Castle or Yellow sandstone.
II. Upper Ludlow Group	D. Upper Whitcliffe or Chonetes flags.
	C. Lower Whitcliffe or Rhynchonella flags.
I. Aymestry Group	B. Mocktree or Dayia shales.
	A. Aymestry or Conchidium limestone.

A few typical sections summarized from those given by Elles and Slater will serve to bring out the relations between the eurypterid-bearing beds, and the strata containing other groups of organisms. On the right bank of the Teme River near Ludlow Castle a section is exposed showing the beds from the Aymestry Limestone through the Downton Castle sandstone. Just a little south of Dinham Bridge which crosses the Teme, less than half a mile west of Ludlow, the Aymestry limestone is seen. This is characterized by *Pentamerus knighti*, *Encrinurus punctatus* and other typical forms. This massive limestone is succeeded by the Mocktree or *Dayia navicula* shales, which in turn are followed by the Lower Whitcliffe flags with abundant *Rhynchonella nucula*, *Orthis lunata* and more rarely *Chonetes striatella*. The latter fossil becomes dominant in the Upper Whitcliffe flags which, together with the succeeding beds, are well exposed in the famous Ludford Lane now known as the Whitcliffe Road section, near Dinham Bridge. *Chonetes striatella* "literally swarms" in these flags, and *Orbiculoidea rugata* and *Orthoceras bullatum* are likewise prolific. It is these flags which show the first traces of fragments of that little known eurypterid, *Pterygotus problematicus*, which occurs in the thin shales and sandstones with *Spirifera elevata*, *Chonetes striatella* and *Orbiculoidea rugata* (see fig. 15). The shales and sandstones carrying the fauna just mentioned, are only four feet thick, yet eight changes in sedimentation are shown, marking a rapid alternation of mud and sand deposition which is clearly indicative of near-shore conditions. Immediately overlying this series is the topmost member of the series, the Ludlow Bone-Bed which though never more than a foot in thickness, is yet one of the most noted of the formations of Britain. It has been the subject of description and speculation for seventy-five years or more; but, so far as I know, its origin has never been satisfactorily accounted for (see proposed explanation below, p. 158). Elles and Wood describe the appearance of the Bone-Bed in this section as follows: "It is best developed at the lower end of the section, on the south side of the road where it is 2½ feet above road-level, and reaches a maximum thickness of nearly 6 inches. It is, however, very commonly separated into two thin bands of 'bony' material, divided by a few inches of soft mudstone. These bands occur in a more or less lenticular manner, and one or the other disappears almost entirely from time to time, even within the short distance occupied by the section (72 yards). This feature is characteristic of all the bone-beds of these highest Silurian rocks. In addition to the numerous fish-remains and crustacean remains which the Bone-Bed contains, we have identified *Chonetes striatella*, *Orbiculoidea rugata*, and *Orthis sp:* a similar fauna, with *Beyrichia* in addition, being found in the softer mudstone separating the 'bony layers.' " (61, 203).

Above the Bone-Bed there is a physical and faunal change, the sediments are coarser, sandstones predominating, with only thin interbedded shales, while the genera of brachiopods so characteristic of the strata of the Aymestry and Lower Ludlow have almost vanished

with the exception of the Lingulae. Life on the whole became scarce, only the fish, crustacean, and eurypterid remains occurring in any abundance, and these, as is customary, only at certain horizons. The mottled sandstones and shales immediately overlying the Bone-Bed and forming the base of the Downton Castle sandstones is practically barren. Then follows a thin band with Beyrichia which gives place to the Platyschisma bed proper (E b) which is composed almost entirely of *Platyschisma helicites* and *Modiolopsis complanata*. This band is delimited upwards by a second Beyrichia zone. Finally, the massive, yellow, micaceous sandstones of the typical Downton appear (E c). These show leaf-like shale partings with Beyrichia, and other beds with fragments of eurypterids together with the plant (a spore?) *Pachytheca*, and with *Lingula minima*.

The Temeside or Eurypterid shales (F) are not seen in the Ludford Lane section in which even the Downton group is incomplete. It is not possible to find a continuous section at any one place; but the contacts between each pair of the groups have been seen, so that by combining the sections exposed within a distance of about four miles the entire sequence may be obtained. The contact between the Downton Castle sandstones and the Temeside shales may be seen at Forge Bridge, a little over half a mile northeast of Downton Castle; and the junction between the Temeside group and the Old Red sandstone is visible at Tin-Mill Race about half a mile beyond Forge Bridge. The contact of the lowest division of this group (Fa) with the underlying Downton Castle sandstones is not here observable. The first beds are rubbly shales which, a short distance up, contain a band of red shale. At a higher level occurs a local bed containing broken *Lingula cornea*, *Onchus teniustriatus*, Ctenacanthus-like spines and *Leperditia* cf. *marginata* (**61**, 211). There follows a thin sandstone bed, and then a grey shale with *Lingula cornea*, above which comes the typical olive-shale of F d with the Temeside Bone-Bed which is very similar to the Ludlow Bone-Bed. From this horizon Elles and Slater record the following interesting fauna (**61**, 211):

Pterygotus ludensis
P. problematicus
Onchus teniuistriatus
O. murchisoni
O. sp.
Lingula cornea

Ctenacanthus sp. (?)
Cephalaspis sp. (?)
Pachytheca sphaerica

The olive shales above the Bone-Bed also contain many fragments of eurypterids. Evidence of the approach of the Old Red sandstone deposition is seen in the frequent occurrence of grit bands in the olive shales. The top of F f is the "Fragment-Bed" which is crowded with fragments of carbonaceous material whose origin is uncertain, and this layer is everywhere succeeded by the purple-red sandstones of the Old Red.

These sections show the typical lithological and faunal characteristics of the Ludlow in England, and they offer unquestionable evidence for a change from marine to continental conditions of sedimentation. Beginning with the Aymestry group which is a pure marine limestone in the lower part, passing up into shales with thin limestone beds, the succession continues through the flags of the Upper Ludlow group, terminated by the Ludlow Bone-Bed, and finally the Temeside group closes the Siluric. These last beds consist of the Downton Castle sandstones in the lower half, which show an alternation of unfossiliferous sandstones and shales with beds of similar character bearing Lingulas or Platyschisma, or eurypterids or fish remains, while the upper portion constitutes the Temeside or Eurypterus-shales which are dominantly eurypterid-bearing, olive shales, with intercalated grit bands, fish beds and bone-beds. In regard to these formations in the Ludlow-Downton district, Elles and Slater make the following significant statement: "Palæontologically, these rocks are characterized by the presence of Eurypteridae, which, although rare in the lower beds, gradually increase in importance until they attain their maximum development in the beds immediately underlying the Old Red sandstone. The rich brachiopod-fauna, characteristic of the lower beds, dwindles and almost dies out with the approach of shallow-water conditions, although the molluscs are somewhat more persistent" (37, 197). The eurypyterids occur in thin seams not associated with the fast diminishing marine fauna, but with crustacea such as Beyrichia, with the thin-shelled *Platyschisma helicites* and occasional Lingulas, and especially with fishes. The eurypterids are scarce in the Aymestry and Upper Ludlow groups, but become abundant in certain layers in the Temeside group where they are found in cross-bedded sandstones, in bone-beds, and characteristically, in olive-colored shales.

The physical and faunal characteristics which have just been described have usually been interpreted as indicative of shallow-water marine conditions of sedimentation during the late Siluric. The physical nature of the Temeside group would, perhaps, not preclude such an origin, but the faunal characters leave no doubt that the Temeside group must have been deposited on the land. As is so frequently the case in such successions of sands and flags, there is no doubt that the material is terrigenous in origin, the only question being the place of deposition, whether on the land or along the littoral margin of the sea. If we apply the criteria for the recognition of the various types of fossil faunas, it is at once evident that neither throughout the Temeside group nor at any particular horizon in it is there a marine fauna, for we have seen that a marine fauna, whether existing under the rather uniform conditions of the open sea or under the more variable environment of the littoral zone, and whether in a sandy, muddy, or pure water facies, was yet made up of diverse classes of organisms with a scattering representation through the phyla of the Invertebrata. In the Temeside group there is no bed containing representatives of more than two invertebrate phyla and usually only one phylum is represented. The maximum thickness of this group is 170 feet. In the lower 50 feet (Downton Castle sandstones) the deposits are cross-bedded and contain *Lingula minima* at certain levels, but no other fossils. Such a series is to be accounted for only by deposition at the mouth of a river, either on the subaërial portion of a delta or on the flood-plain, but the coarseness of the deposits implies that the former was the more probable region of deposition. The presence of beds of Lingulae is easily accounted for by the nature of the shells which are thin, corneous, and consequently of small specific gravity. Exceptionally high tides would easily wash in such light shells far up over the delta, while heavier shells would be dropped farther out in the littoral waters. It is evident that the Lingulae must have been transported from their original habitat since they are unassociated with any other forms of life, unless they can be regarded as living in the river mouths. Thus the assortment seems to have been by specific gravity. In the 120 feet of the Temeside group, *Lingula cornea* replaces *L. minima* in the single bands, and is to be accounted for in a similar manner. Now it might be suggested that the eurypterids, which are likewise found in thin bands, were also washed in from the sea on account of their light specific gravity; but the difference between the two cases is that the Lingulae are found in abundance in the marine littoral fauna where they occur, normally associated with marine species of molluscs, crustacea, etc., in the marine deposits of the same age further south; furthermore, Lingulae are found from the Cambric to the present in undoubted marine associations. The eurypterids, on the other hand, are not found in the unequivocal marine deposits to the south, but appear quite as suddenly as the Lingulae, although in separate bands. They have been found to the north of the Ludlow area in Scotland, always as concomitants of the transition from marine to continental conditions, and it is only when the latter conditions transgress farther and farther south that the eurypterids appear.

I think that much light will be thrown upon the interpretation of the late Siluric deposits in England by the study of the Ludlow and higher bone-beds. It will not be possible in this paper to consider the habitat of the early fishes except incidentally, but if that is proved to be fluviatile, as I think it may be, then the following explanation may be offered for the bone-beds. The Ludlow Bone-Bed, which is the most constant and widespread, appears to mark the wholesale destruction of the fishes in the rivers at the time when, in the oscillatory movements preceding and accompanying the retreat of the sea, there were temporary advances. The salt water, pushing its way up the rivers, killed the fishes and other river organisms in great numbers, for the fluviatile fishes can less easily survive an influx of salt water than marine fishes can an influx of fresh water. This is implied in Günther's statement that "On the whole, instances of marine fishes voluntarily entering brackish or fresh water are very numerous, whilst fresh-water fishes proper but rarely descend into salt water" (97, 187). Thus during the oscillations preceding a negative eustatic movement, the sea would occasionally advance a short distance over the land, and if this temporary positive movement were widespread, bone-beds would be formed at or near the mouths of many rivers almost contemporaneously, and even if some areas were submerged and others not, geologically the bone-beds would appear to be approximately synchronous. This theory is borne out by the occurrence of thin bone-beds at a number of higher levels in the beds above the Ludlow Bone-Bed. Moreover, whenever there was a slight retreat of the sea with the pushing forward of terrigenous, coarse material, then the light Lingula shells might well be left stranded along the line marking the high-water level for that particular period. If such a negative movement were followed by a slight positive one, with the consequent killing off of the fish, a bone-bed would be formed and in a given section would be found overlying a Lingula bed, as does the Temeside Bone-Bed (F d). Were the sea to retreat again, more Lingulae would be left stranded, while fluviatile organisms that were light enough might be floated out across the flood-plains of the rivers. These flood plains had but just been retrieved from the sea and would have been so slightly raised above sea level that only lighter organic remains such as the Lingulae were washed over it, thus fluviatile remains of small specific gravity would be carried out across the flood-plain there to come to rest with the Lingulae, and in this way the olive shales with eurypterid fragments and *Lingula cornea* would be easily explained. The impossibility of considering either fish or eurypterids as washed in from the sea is indicated by the absence of these forms in the open marine waters to the south. While I have made no attempt to prove the fluviatile habitat of the fishes, yet the bone-beds seem capable of explanation on no other hypothesis. Sometimes the beds are only ¼ inch thick, containing no complete remains but only a great mass of broken bones, spines, and scales. Such an accumulation could be formed only of transported material, the fish skeletons having been entirely scattered. If a bone-bed were accounted for as due to the sudden destruction of fishes in the sea by a current of colder or more saline water, by an earthquake or some other catastrophic calamity, then the fish would die in great numbers, but their remains would be buried in situ. An illustration of this is found in the case of the tile fish off the New England coast, where, in 1882, according to estimates, over one billion fish were destroyed, and the ocean floor was covered in this region to a depth of 6 feet with the bodies of the dead tile fish (Grabau, **87**, 195). Entire skeletons would be preserved in the rapid burial, and other marine organisms which suffered the same fate as the fish would also be entombed, so that the resulting deposit would in no way resemble the bone-beds, which are made up of fragments, usually so broken that identification cannot be made, while marine shells are only rarely found.

THE LUDLOW AND LANARKIAN OF LANARKSHIRE. The inliers of Siluric rocks are larger in Lanarkshire than in the Pentland Hills, and the succession is shown more completely, for in Lanarkshire the structure is anticlinal, while in the Pentland Hills the beds have been repeatedly faulted and stand nearly vertical, making it impossible to trace an outcrop except along the strike. About 5500 feet of Siluric strata are exposed, ranging in age from questionable Wenlock, through the Ludlow and Lanarkian (Downtonian) and into the volcanic series of the Lower Old Red sandstone. The eurypterids are found in many more localities than in the Pentland Hills, but they are never so abundant nor are so many genera and species represented. There are four important Siluric areas in Lanarkshire, but in only two of these have eurypterids been found, namely in (1) the Lesmahagow inlier, and (2) the anticline of the Hagshaw Hills.

(1) *The Lesmahagow Inlier*. This is the larger of the two anticlines and extends from a little north of Muirkirk northeast for 6 miles. The Greenock Water in the southwest and the Logan Water in the northeast have exposed a number of excellent sections in the gently dipping beds. The lowest beds exposed consist of a series of blue greywackes with shale partings, the whole comprising 1300 feet as seen along the southern margin of the area along the headwaters of the Ponesk and Nethan. Only a few specifically unidentifiable fossils have been obtained from this series which is provisionally placed with the Wenlock. Immediately to the north of these beds occur grey, blue and olive shales, with occasional nodular greywacke bands yielding a good representation of lowest Ludlow fossils.

The third subdivision recognized by Peach and Horne constitutes the so-called Ceratiocaris beds which are of particular significance because of the surprising abundance in some places of several species of Ceratiocaris, and because of the occurrence of the Ludlow fish, *Thelodus scoticus* in one layer and finally because of the association of eurypterid remains with both of these. At many different points along the Logan Water the beds are excellently shown. In a small gorge about three-quarters of a mile to the northeast of Logan House the lowest of the Ceratiocaris beds dipping to the northwest are succeeded by some zones of dark, fissile calcareous flaggy shales which weather a rusty brown and which have yielded the following fossils:

Worm tracks
Ceratiocaris laxa Woodw. and Jones
Ceratiocaris longa Woodw. and Jones
Ceratiocaris papilio Salter
Ceratiocaris stygius Salter
Ceratiocaris telson, like *murchisoni* M'Coy
Slimonia acuminata Salter

In the same shale band about a half a mile distant the following fossils were found, the eurypterids occurring in great abundance, but the Ludlow fish *Thelodus scoticus* being represented by only two fragments (**215**, 573):

Myriopoda ? (impressions of)
Ceratiocaris sp.
Dictyocaris ramsayi Salter
Pterygotus bilobus Salter
Slimonia acuminata Salter
Thelodus scoticus Traq.

In certain members of the Ceratiocaris group, though a little below the fish horizon, there are recorded from Long Burn, a tributary of Logan Water, the following species:

Modiolopsis nilssoni (His.)
Spirorbis sp.
Beyrichia kloedeni (M'Coy)
Beyrichia kloedeni var. *torosa* (Jones)
Lingula minima (Sow.)
Orthonota sp.
Ceratiocaris
Dictyocaris ramsayi (Salt.)
Pterygotus bilobus (Salt.)
Platyschisma (*Trochus*) *helicites* (Sow.)

The best development of the Ludlow fish band occurs about ½ mile south of Logan House in which place also was found an excellently preserved scorpion *Palaeophonus caledonicus*. In the same place in a cliff about 30 feet high a good section is exposed, showing hard greywacke bands at the top, but below these are brown flaggy shales containing Ceratiocaris in abundance and a few Pterygotus fragments. Embedded in these shales are ironstone nodules which contain fish remains. From this outcrop the following fossils have been collected (**215**, 574):

Archidesmus loganensis Peach
Ceratiocaris longa Jones and Woodw.
Ceratiocaris murchisoni ? M'Coy
Ceratiocaris papilio Salter
Ceratiocaris stygius Salter

Slimonia acuminata Salter
Physocaris sp.
Pterinea retroflexa Wahl.
Platyschisma (*Trochus*) *helicites* Sow.
Thelodus scoticus Traq.
Thelodus planus Traq.
Fish fragment undetermined

Overlying the Ceratiocaris beds and appearing as a narrow band to the north of them throughout the area is a series of hard blue and grey flaggy shales and mudstone, with occasional calcareous nodules. These constitute the Pterygotus beds, 350 feet thick, and are the ones from which Dr. Slimon of Lesmahagow made his extensive collections. The best section is along the Logan Water which for quite a distance runs along the strike of the beds. On the right bank about 400 yards west of Dunside the following fossils have been collected (215, 575):

Ceratiocaris papilio (Salt.)
Neolimulus falcata (Woodw.)
Eurypterus lanceolatus (Salt.)
Eurypterus obesus (Woodw.)
Eurypterus scorpioides. (Woodw.)
Pterygotus bilobus (Salt.)
Pterygotus bilobus var. *acidens* (Woodw.)
Pterygotus bilobus var. *inornatus* (Woodw.)
Pterygotus raniceps (Woodw.)
Slimonia acuminata (Salt.)
Stylonurus logani (Woodw.)
Lingula minima (Sow.)

"In a small tributary of the Logan Water from the north, at a spot about 250 yards west from Dunside, these flaggy shales have yielded specimens of *Spirorbis lewisi*, *Beyrichia kloedeni*, *Dictyocaris slimoni*, *Pterygotus bilobus*, *Slimonia acuminata* and *Platyschisma helicites*."

In several others of the tributary burns the eurypterids are found associated always with Ceratiocaris or Dictyocaris, *Beyrichia kloedeni* usually and sometimes lingulas.

Still higher horizons of the Ludlow, numbers 5 and 6 of Peach and Horne's subdivisions have yielded eurypterid remains in the basin of the Greenock Water. From the sand greywackes and greenish shales E. N. E. of Waterhead the following fossils are recorded (**215**, 576):

Slimonia acuminata (Salt.)
Beyrichia kloedeni (M'Coy)
Dictyocaris sp.
Spirorbis lewisi (Sow.)
Goniophora cymbaeformis (Sow.)
Modiolopsis complanata (Sow.)
M. nilssoni (His.)
Orthono'a impressa (Sow.)
O. rotundata (Sow.)
O. solenoides (Sow.)
Platyschisma helicites (Sow.)

Following upon the highest of the Ludlow green flaggy and sandy greywackes there is in many localities a conglomerate of varying thickness conformable, so it is stated, upon the Ludlow. In the Lesmahagow inlier, however, this conglomerate is absent. On the northwest slope of the anticline the transition beds are exposed in many places showing the change from greywackes to cross-bedded red and yellow sandstones, 1300 feet thick, and constituting subdivision 8. Overlying this is a group of strata, about 100 feet in thickness, containing the very important fish-band. Sections along the Dippal Burn and various streamlets emptying into the Glengarel and Kype Waters show the succession. The fish-band itself is only from 12 to 15 feet thick, comprising an alternating series of brown flaggy carbonaceous shales and green mudstones. It is in the former that the fishes and eurypterids occur, but no organic remains have been found in the mudstones. There are many sections from which the fish and eurypterids have been obtained, but two will suffice to show the nature of the fauna. Near the head of Dippal Burn there have been obtained (**215**, 578):

Eurypterus dolichoschelus (Laurie)
Ceratiocaris sp.
Lanarkia spinulosa (Traq.)
L. horrida (Traq.)
L. spinosa (Traq.)
Thelodus scoticus (Traq.)
Birkenia elegans (Traq.)

Pachytheca
Parka n. sp.
Fucoid-like markings

One of the two best localities for ichthyolites and the one in which all of the species of Downtonian fish determined by Dr. Traquair have been found is in the Slot Burn, one of the tributaries of the Greenock Water. The fossils thus far described from there are (**215**, 578):

Eurypterus dolichoschelus (Laurie)
Stylonurus ornatus (Laurie)
Myriopod
Lanarkia spinulosa (Traq.)
L. horrida (Traq.)
L. spinosa (Traq.)
Thelodus scoticus (Traq.)
Birkenia elegans (Traq.)
Lasanius problematicus (Traq.)
Ateleaspis tessellata (Traq.)
Ceratiocaris laxa (Jones & Woodw.)
Dictyocaris sp.
Pachytheca sp.
Plant stems.
Sponge?

A second fish band yielding several species of fishes and a myriopod has been found a short distance up the Slot Burn and at a slightly higher horizon than the main one; eurypterids have not yet been found in it.

An excellent section in the eastern area of the Lesmahagow anticline is shown in the Birkenhead Burn, a tributary of the Logan Water. The passage from the Ludlow to the Downtonian is obscured by a normal fault which abruptly truncates the Ludlow series, but the rest of the succession is complete. The total thickness of the fish-band with the intercalated mudstones is here fifteen feet. The lowest fossiliferous carbonaceous seam is about a foot thick, while higher up in the band the seams vary from one to six inches. "The remarkable feature of this exposure is the constant association of the fish fauna with eurypterids that are characteristic of the underlying Upper Ludlow rocks." The fossils listed are (**215**, 580):

Eurypterus sp.
Pterygotus bilobus ? (Salt.)
Lanarkia horrida (Traq.)
L. spinosa (Traq.)
L. spinulosa (Traq.)
Slimonia acuminata (Salt.)
Stylonurus sp.
Thelodus scoticus Traq.
Ateleaspis tessellata (Traq.)
Ceratiocaris sp.
Birkenia elegans (Traq.)
Lasanius problematicus (Traq.)
Plants
Sponge

2. *The Anticline of the Hagshaw Hills.* About five miles to the south of the Lesmahagow anticline rises the crest of the Hagshaw Hills anticline, the axis trending northeast southwest. The area between the two anticlines is occupied by a northern belt of limestone, Mississippic in age (Calciferous limestone of Scottish geologists), and by a southern area of Lower Old Red sandstone with one patch of Upper Old Red. Rising above these is the anticline forming the Hagshaw Hills, where the Wenlock, Ludlow and Downtonian are exposed by erosion. It is only in the northern limb of the anticline that the Wenlock and Ludlow are visible, for the southern has been cut off by a thrust fault along the plane of which the older Siluric rocks have been brought to rest against the younger ones. The Douglas Water and its many small tributaries have exposed a number of good sections in the western area of the anticline. One of the best of these is in the Ree Burn, south of the Glenbuck Reservoir where there is an almost continuous section of the Ludlow rocks. At one point in certain blue finely bedded shales and flaggy greywackes specimens of Ceratiocaris, Slimonia and *Beyrichia kloedeni*, have been found. Along the southeastern slope of the anticline where the Podowrin Burn joins the Douglas Water near Monksfoot a transverse section of the Ludlow rocks is shown. They are greywackes and flaggy shales and are thought to be the equivalent of the lowest Ludlow in the Lesmahagow area. It has not been possible to obtain any definite statement as to the exact horizons in which the fossils occur and whether the eurypterids occur as they

do elsewhere in bands distinct from the layers containing molluscs, brachiopods, etc. From this locality the Ludlow beds have yielded the following fossils (**215**, 583):

Slimonia acuminata (Salt.)
Beyrichia kloedeni (M'Coy)
Ceratiocaris papilio (Salt.)
Favosites asper (D'Orb.)
Lindströmia sp.
Glyptocrinus basalis (M'Coy)
Crinoid stems
Ceriopora sp.
Strophomena (*Leptaena*) *rhomboidalis* (Wilck.)
Ctenodonta sp.
Cornulites sp.
Calymene blumenbachii (Brong.)
Encrinurus sp.
Illaenus sp.
Proetus stokesi (Murch.)
Athyris (*Glassia*) *compressa* (Sow.)
Orthis bouchardi (Dav.)
O. (*Dalmanella*) *elegantula* (Dalm.)
O. polygramma (Sow.)
Orthonota sp.
Orthoceras angulatum (Wahl.)
O. small smooth sp.

Along the Smithy Burn, the West branch of the Podowrin Burn, Mr. Tait found a brown sandy shale which because of the abundance of the Bryozoan Glauconome has been called the Glauconome band. This immediately overlies the fish beds and contains (**215**, 585):

Eurypterus dolichoschelus (Laurie)
Glauconome disticha (Goldf.)
Lasanius problematicus (Traq.)
Ateleaspis tessellata (Traq.)
Spirorbis sp.
Sponge
Pachytheca sp.

The Lanarkian series is typically developed along the northern limb of the anticline from the local conglomerate at the base found only in the Hagshaw Hills to the chocolate-colored sandstones at the top, but the only bed of particular interest in the present discussion is the fish band which has been found in several places. In the Monk's Water, about three-quarters of a mile south of Monkshead, the following fossils are reported from this band:

Eurypterus, small sp.
Scorpion
Ceratiocaris ?
Thelodus scoticus (Traq.)
Birkenia elegans (Traq.)
Lanarkia spinosa (Traq.)
L. spinulosa (Traq.)
L. horrida (Traq.)
Lasanius problematicus (Traq.)
Sponge?

II. THE OLD RED SANDSTONE

HISTORY AND SUBDIVISION. The closing stages of the Siluric in northwestern Europe were marked by an expansion of the continental areas and an accompanying widespread retreat of the sea which left all of Great Britain except the southwestern portion of Devonshire, all of Scandinavia, Finland, and the northern borders of Germany dry land. Over the region thus exposed was deposited a great series of conglomerates, sandstones, and shales, dominantly red in color, and reaching a thickness of many thousands of feet, the formations being collectively called the Old Red sandstone facies of the Devonic. It was early recognized that the conditions of sedimentation under which these deposits accumulated were essentially different from those under which the marine Devonic limestones of Russia, western Europe, and extreme southwest England were formed. Not only did the tremendous thickness of the beds attract attention, but the coarseness and prevailing red color of the deposits, and particularly the almost entire absence of organic remains, caused considerable speculation on the part of continental as well as British geologists on the origin of this remarkable series. In the early part of the last century the suggestion was made by Dr. John Fleming that the Old Red might have been deposited in lakes. This theory was eagerly taken up first by Godwin-Austen (6) in 1855 and by a host of later writers, each one of whom contributed some bit of evidence, be it palæontological, geographical or stratigraphical, to show that these Devonic red beds were laid down in lakes. The attempt to prove this theory has, as is so often the case in the development of science, led to careful observations by many men, to the formulation of alternative theories and to the collection of a great mass of valuable data. That the first theory may perhaps prove incorrect is of small importance compared to the fact that it made geologists realize that there was a problem to be solved, and spurred them on to its solution. This lacustrine theory, however, has had a longer life than is usually allotted to first theories, for it has held on to the present day and still has more adherents than has any later hypothesis. The monograph by Sir Archibald Geikie "On the Old Red Sandstone of Western Europe," published in 1878, embodied such an elaborate discussion of the various lakes of the Devonic period and so many field observations were adduced to back up the theoretical statements that later writers have with few exceptions considered that the lacustrine origin for the Old Red sandstone was proved beyond any further question. To be sure, one or two heretical geologists have raised objections to these ancient lakes and have preferred to think that the Old Red was a marine deposit formed under particular and inimical conditions. Within the last ten years both of these interpretations have been questioned by not a few, and although the majority of geologists unhesitatingly accept the older ideas, particularly favoring the lacustrine theory, nevertheless, there is an ever-increasing tendency at the present time to recognize the fact that all continental formations need not necessarily be deposited in large bodies of standing water. Thus the ultra-modern school of geologists champions the importance of fluviatile deposits in the past, insisting especially upon the fact that such deposits are spread out in large part on the land and not in lakes or inland seas. This school of "terrestrial" as opposed to "aqueous" geologists, found its earliest leaders in Johannes Walther and Albrecht Penck, later disciples in this country being Professors Grabau and Barrell. The last two as well as Walther and Goodchild have argued the dominantly continental origin of the Old Red sandstone, Professor Grabau arguing on the basis of the field evidence and on lithological and palaeontological grounds; and Professor Barrell from the standpoint of the physical conditions which must have prevailed at that time. These various theories will presently be taken up and the evidence for each will be discussed.

The present outcrops of the Old Red sandstone in the British Isles are for the most part discontinuous and decidedly patchy. They fall roughly into five areas (see index map, fig. 16): (1) The Caithness-Orkney Islands region with a northward continuation into the Shetlands and a southward one into Sutherland and Rosshire, including the coastal strips on both sides of the Moray Firth; (2) The Forfar-

Fig. 16. Sketch Map of British Isles Showing Distribution of the Old Red Sandstone
(After Lake and Rastall)

shire-Kincardine and Perthshire area, with discontinuous outcrops in northern Argylshire, together with patches along the Caledonian Canal; (3) Scattered outcrops in southeast Scotland and the Cheviot Hills; (4) The southwestern and southern district of Wales; (5) western England together with the southern and southwestern portions of Ireland. The lack of geological and geographical continuity in these sections, the distinctness of the faunas where present, and the complicated tectonic relations, have led to many different classifications which have been made to fit not only the facts observed in the field, but also the hypotheses evolved to account for the facts. Moreover, since the deposits have not been formed in the sea, as I shall demonstrate below, none of the usual criteria for correlation of marine strata are available, and thus in each locality where the formations are described local names are given to the beds and it is impossible to state what are the equivalents elsewhere. The same lithological facies are repeated again and again, there being rapid vertical and lateral changes, but nowhere is the succession twice alike.

The original subdivision of the Old Red sandstone was made by Murchison before the middle of the last century into three groups, as follows:

Upper Old Red or Dura Den beds,
Middle Old Red or Caithness flags,
Lower Old Red or Arbroath flags.

The lower series is typically developed in Forfarshire, where it consists of coarse conglomerates for the most part, though shales and sandstone are also represented. The middle series is the remarkable grey, flaggy facies exhibited in Caithness and carrying the abundant fish fauna, while the upper is a yellow sandstone group found overlying the flags at Dura Den. Murchison's chief reason for making the Lower and Middle separate, even though the two are never found in contact or even in the same locality, was the distinctness of the faunas in the two, for while the fish and eurypterids of the Arbroath flags were generically and sometimes specifically like those in the Upper Siluric, they were entirely different from those in the Caithness flags, a statement which later investigators have strengthened. Geikie, however, contended that the Lower and Middle were synchonous deposits in separate lakes and that the faunas were not entirely distinct, and even today Geikie supports the two-fold division making the Lower include the Arbroath flags and the Caithness flags, while in the Upper are the Dura Den beds, which for the most part rest unconformably upon the Lower Old Red or transgressively on older rocks (Geikie, **74,** 1006).

Dr. Goodchild, who has worked over the Scottish rocks for nearly fifty years, has taken exception to a number of the prevailing ideas about the Old Red and has given a new subdivision. He has returned to a threefold subdivision for these rocks as they occur in Scotland, the divisions corresponding in many respects to those made by Murchison, although he does not use the terms Lower and Middle because they have been employed with such different meanings by various writers that he deems it best to use locality terms. Thus he gives the following subdivisions of the Old Red sandstone in Scotland, the Orcadian succession being based on Traquair's work (**272–275**) on the ichthyology and on Flett's studies (**66**) in the Orkneys (**80,** 600).

Upper Old Red Sandstone:

2. Higher subdivision, or Elgin beds (now known to be Triassic).
1. Lower subdivisions, or Nairn beds. 0–1,000′
   (Extensive unconformity).

Orcadian Old Red:

5. John o'Groats Flags.
4. Thurso or Rousay Beds.
3. Achanarras, Stromness, and Cromarty Beds.
2. Berriedale sandstones.
1. Badbea Breccias and Basal Conglomerate. 0–16,000′

Caledonian Old Red Sandstone:

3. Strathmore sandstones (the upper part of which may be contemporaneous with the lowest part of the Orcadian).
2. {
   Myriopod Beds.
   Volcanic Rocks.
   Acanthodian Beds of Turin Hill.
   Cephalaspis Beds of Auchtertyre.
   Volcanic Rocks.
   Pterygotus Beds of Carmylie, etc.
   Tealing Beds.
1. Lower Series of sandstones, mudstones, conglomerates, etc., base not seen. Ranging to ? 20,000′

(Extensive unconformity).

The Lanarkian Rocks (Downtonians of the Geological Survey, the original Lower Old Red of earlier writers).

Ludlow Rocks.

Mr. George Hickling who has made a special study of the Lower Old Red in Forfarshire, where it is typically developed, has given a somewhat different tabulation (**117,** 398):

	Feet
Edzell shales	1,000
Arbroath sandstone	1,200
Auchmithie conglomerate	800
Red Head series	1,500
Cairnconnon series	2,000
Carmyllie series	1,000
Dunnottar conglomerate	5,000
	12,500

The employment of different names for deposits perhaps synchronous, but occurring in different localities, is inevitable because of the lack of stratigraphical continuity and because the fossils which are found in these rocks are not of the type to serve as good index fossils, if, as I hope to show, they lived in the rivers.

It will not be possible to work out the lithogenesis of the eurypterid-bearing beds in the Old Red by a study of those beds alone; rather must we take a broader view that will lead to an interpretation of the climatic and other physical conditions which obtained throughout the Devonic in the regions where red sedimentation was going on. Having determined what these conditions were, the origin of the sediments, the agents of transportation and especially the nature of the areas in which deposition occurred, i.e. whether under water or on the land, then the character of the faunas and of the restricted beds in which they occur, will automatically be ascertained. A few detailed sections in the type localities will enable us to generalize later on.

The Caledonian. At the end of the Siluric there was a period of folding and erosion, the extent of which is not known, but most of the sections indicate that it was long, and perhaps nowhere has a true gradational contact been found between the uppermost Siluric and the lower Old Red. Goodchild remarks in this connection, "So far from graduating downward into the Silurian rocks, the local base of the formations under notice (the Caledonian) lies with a violent unconformity upon all of these rocks, and may repose indifferently upon Silurian, Ordovician or even older strata, including the metamorphic rocks of the Southern Highlands of Scotland. What has been taken as the Caledonian Old Red in the cases where it has been supposed that a passage exists is in reality a series of quite different age" (Goodchild, **80**, 598, 599). As further evidence of the great break between the two systems Goodchild adds that the Lanarkian rocks shared in all of the tremendous disturbances to which the Siluric rocks were subjected and that "these disturbances had ceased, and had been followed by prolonged denudation, long before the oldest member of the Caledonian Old Red was laid down. Hence it results that the great unconformity, so often referred to, passes above what is left of the Lanarkian rocks. There is no clear evidence of any unconformity below them" (Goodchild, **80**, 599).

Thus from the many sections described in the Scottish literature and especially from the authoritative statement of Goodchild, there seems to be good reason for believing that there was a great unconformity at the end of the Siluric, caused in part by profound tectonic disturbances, and that following upon these there was a long period of erosion before the earliest of the Caledonian deposits were laid down. These were of great thickness, amounting in some places to 20,000 feet. As to the origin of the series Goodchild says: "There appears to be evidence of a satisfactory nature that the whole of the vast formation was accumulated under continental conditions, partly in large inland lakes, partly as torrential deposits of various kinds, partly as old desert sands, and partly as the results of extensive volcanic action" (**80**, 596).

A brief review of the lithological characters and distribution of the Caledonian Old Red series will show most clearly that the rocks throughout are of continental origin. The lowest member, division 1, consisting of sandstones and conglomerates, is often wanting altogether, the overlying volcanics being the first of the series to be present. At the Falls of Clyde, near Lanark, Lanarkshire, these lower beds are, however, to be seen, and they are also found in a few other localities. Generally, the volcanics rest immediately and with a violent unconformity upon various pre-Devonic formations. It is these lavas which are seen in the Ochils and Sidlaw Hills, in the Pentlands and in the vicinity of Oban, at St. Abb's Head and also in the Cheviot Hills. In their greatest development in the Perth and Forfar Hills the volcanics may well reach several thousand feet in thickness, but they thin away toward the north and northeast and pass into alternating sedimentary and igneous rocks which were contemporaneous in their development with the main volcanic outpourings (see sketch map, fig. 17).

The first important fossiliferous beds are those found at Carmylie and adjoining localities in Forfar. These constitute a part of the famous Arbroath flags and because of their abundant eurypterid remains are called the Pterygotus beds. In them are found the most perfect specimens of *Pterygotus anglicus*, though complete individuals are rare, and the rock often contains also an abundance of *Parka decipiens*, which has been variously identified as crustacean egg cases and as spores of plants. Above these beds follows the main mass of the lavas upon which rest the beds of Auchtertyre, which

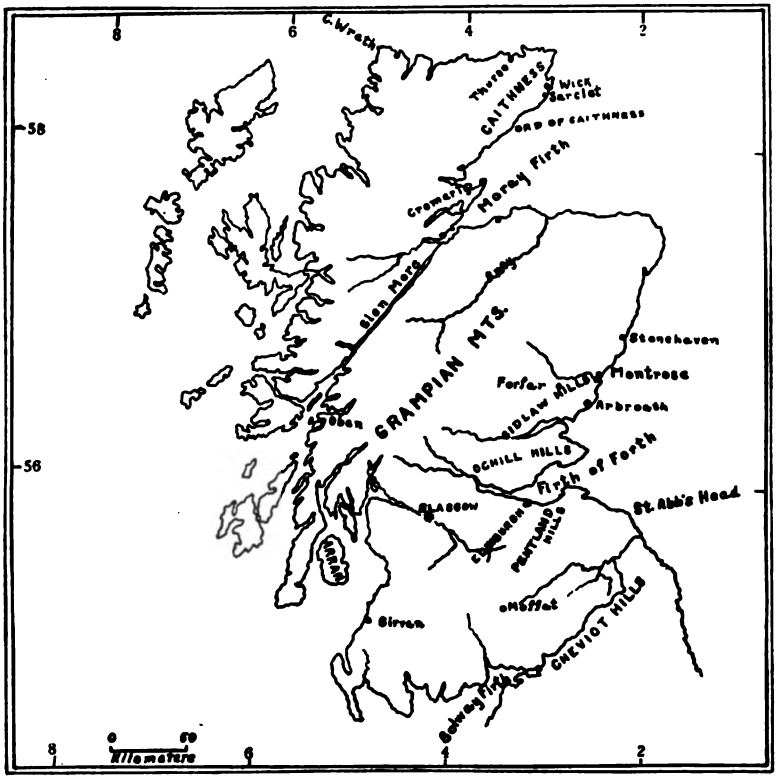

Fig. 17. Sketch Map of Scotland, Showing Localities where Old Red Sandstone Outcrops

have yielded *Cephalaspis lyelli*, *Pteraspis mitchelli*, and certain of the Acanthodian fishes. At a slightly higher horizon and contemporary with some of the volcanic beds is the Acanthodian zone which is best seen at Tilliewhamland Quarry, Turin Hill, near the town of Forfar. The list of fossils from these beds cited by Goodchild is as follows (**80**, 597):

Mesacanthus mitchelli
Ischnacanthus gracilis
Climatius scutiger
C. uncinatus
C. reticulatus
Parexus recurvus
P. falcatus
Euthacanthus mitchelli
E. elegans
E. gracilis
E. curtus
Cephalaspis pagei
C. asper
Thelodus pagei
Pterygotus anglicus
Stylonurus ensiformis
Parka decipiens

Just above the top of the volcanic series has been found a fossiliferous zone yielding myriopods among which are Kampecaris and Archidesmus, as well as some poorly preserved plants referred to *Psilophytum robustum*. The top of the Caledonian Old Red is formed by the Strathmore sandstones which are well developed in the Strathmore lowland of Forfar, but the exact age of which is difficult to determine because of the lack of fossils. It has been thought that they might be contemporaneous with the oldest beds of the Orcadian division, but conclusive evidence is lacking.

The Siluric Stonehaven beds of red sandstone and interbedded bright red shales are exposed in the neighborhood of Stonehaven and are about 1500 feet thick. Upon these follows the Dunnottar conglomerate, 5000 feet thick, of coarse red and grey sandstones, grits and conglomerates in which occur pebbles which commonly "range up to a foot or more in length, and yet are astonishingly well rounded. They mostly consist of quartzite" (**117**, 399). Interbedded lavas occur in the top of the series and are succeeded by the Carmylie beds, about 1000 feet thick, of compact red or grey sandstones with some flags, which are the Acanthodian beds described by Goodchild and which contain the abundant fish and eurypterid remains. This series, together with the contemporaneous lavas, forms the backbone of the Sidlaw Hills. It grades up into the Cairnconnan series of 2000 feet of dull red or grey grit with bands of conglomerate. The succeeding Red Head series, 1500 feet thick, consists in the lower part of "fine red thin-bedded sandstone with bands of hard bright red shale, while the upper portion is made up of thicker-bedded sandstone." Six or seven miles south of the Red Head promontory from which the beds are named, there is a lithological change to blue or grey shales with sandstone partings, illustrating well the rapid lateral variation. Overlying this group is the Auchmithie conglomerate. "The series consists of three main masses of conglomerate, with intervening sandstones and conglomerates. The pebbles in the conglomerates are well rounded, fairly large (generally 1 to 6 inches, rarely 12 inches), and, as usual, are mostly quartzite" (**117**, 400). This conglomerate is 800 feet thick and is followed by the highest member of the series, the Arbroath sandstone (1200 feet). "Coarse, gritty sometimes pebbly sandstone is its component rock, always red in color" (**117** 400). The succession as here shown in Forfarshire shows beyond a doubt that the sediments could not have been marine. The complete series is shown in outcrops in Forfarshire, extending over about 500 square miles, while within a distance of less than ten miles the outcrops of all of the formations may be seen.

The Orcadian. Over the greater part of northeast Scotland and extending northward to the Orkney and Shetland Islands there is developed a great series of flags, sandstones and conglomerates younger in age than the Caledonian and these have been called the Orcadian by Goodchild. They constitute the Lower Old Red as used by Geikie and were thought by him to have been deposited in the large water body which he called Lake Orcadie. Neither the natural base nor top of the series has been seen and even the highest members are always followed unconformably by the Upper Old Red. It is unnecessary to take up the formations in detail because they do not contain eurypterids. There are three fossil horizons containing, with one exception, only fish remains. These horizons are the Achanarras beds, the Thurso flags and John o'Groats flags.

Goodchild in summarizing the conditions which obtained in Orcadian time says: "There is evidence that, during the time when the Orcadian Old Red was in course of being deposited, normal pluvial conditions obtained for a time. The deposition of ferric oxide in the old area of inland drainage ceased, chiefly in consequence of the large quantities of vegetable matter which were swept into the old lakes. This latter, in its turn, decomposed the solutions of sulphate of lime, and liberated the calcareous matter, which in a state of diffusion, or aggregated into nodules, now forms so conspicuous an element in the Orcadian Rocks. Furthermore, the sulphate of lime, in its turn, converted the vegetable matter into the bituminoids, which, in a diffused form, permeated—one might almost say saturated—so much of the Caithness Flagstones. I hold, therefore, that the exceptional durability of the Caithness flagstones, which of course is due to the large percentage of bituminous matter they contain, is due to the fact that conditions of inland drainage, one of the phases of desert conditions, prevailed where these occur during the Devonian Period" (**80**, 220).

THEORIES OF DEPOSITION. From data of the type just given, three theories have been evolved, each based upon practically the same observations in the field, but each involving very different interpretations. The oldest and most widely accepted explanation for the Old Red sandstone is that it is a series of lake deposits; the second theory, which quite rightly has never received very much attention, is that of marine deposition; the newest hypothesis is that the Old Red is dominantly of fluviatile origin and that the deposits were not laid down in any permanent body of standing water, either marine or fresh, but largely on the dry land as torrential and flood-plain deposits or in evanescent playas. I shall briefly consider the first two theories and the objections thereto, and shall then give the third and some of the evidence favoring it. All geologists are agreed that the sediments are clastic, that they were not deposited in the deep sea, that they are land-derived and river-transported; the only point of difference that has arisen is in regard to the locus of deposition.

Deposition in Lakes. This theory has been most fully expounded by Geikie and has been generally accepted in the form in which he gave it. For the British area he recognized five lakes on the basis of the present outcrops, considering that the heavy conglomerates marked the rocky lake shores of Devonic time, while finer deposits pointed out the central portions of the lakes. The presence of desiccation fissures and other structural features to be mentioned below was taken as indicative of the mud flats along shore, which were from time to time inundated by the waters of the lake. Plant, insect, and crustaceous remains, as well as the abundant fish fauna, were correctly pointed out as showing the near presence of land. The distinctness of the fish and merostome faunas in the Caledonian and Orcadian rocks was cited as proof of the distinctness of the lakes in which these organisms had lived. It is surprising, and therefore, worthy of note, that Geikie came so very near to the recognition of the Old Red fish and eurypterids as river dwellers that one marvels at his not having reached that conclusion. The arguments which he cites to account for the differences of the ichthyic fauna of his Lake Orcadie and Lake Caledonia, which were supposed to have been separated by the Grampians, are illustrations taken from modern river faunas; and, if application were made directly to the Old Red faunas, one would have to say that the fish in the two Devonic lakes were different because they came from rivers whose headwaters were separated by a divide. I shall give Geikie's statement in order to show how near he came to the discovery that the Old Red Fauna came from the rivers, and how he failed to realize this because he was so intent on the theory of lakes.

"In the second place," he says, "there does not seem to be any valid reason why the ichthyic fauna of two adjacent but completely disconnected water-basins should not have differed considerably in Old Red Sandstone times, as they do at the present day. Even in the same river-system it is well known that the fishes of the higher portions of the basin are sometimes far from corresponding with those in the maritime parts of the area. Neighboring drainage-basins, divided by a comparatively unimportant watershed, sometimes show a remarkable contrast in their fishes. This has been well pointed out by Professor E. D. Cope, in a suggestive paper "On the Distribution of Fresh-water Fishes in the Alleghany Region of South-western Virginia."[13] The James and Roanoke rivers descend the eastern slope of the continent and discharge into the Atlantic. In their upper waters they have only four species of fish in common. In the upper waters of the rivers Holston and Kanawha, which flow south-westwards into the Mississippi basin, there are only two species alike. Between those eastern and western pairs of rivers runs the more marked water-parting of the Alleghany chain. Out of fifty-six species

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[13] *Journ. Acad. Nat. Sci., Philadelphia*, vi, 2d series (1860–69), p. 207.

of fish obtained from the head waters of the four rivers, five were found by Mr. Cope on both sides of the water-shed. There is likewise considerable disparity in the genera represented in the different rivers. The still more important barrier of the Rocky Mountains separates ichthyological areas yet more sharply marked off from each other. Such isolated basins as Lake Baikal, Lake Titicaca, and the Caspian Sea show by their peculiar assemblages of fishes how much ichthyic types may be modified by prolonged isolation. The differences, therefore, between the fauna of Lake Orcadie and Lake Caledonia during the Old Red Sandstone, as I venture to hold, are not incompatible with the idea that the two lakes were in a general and geological sense contemporaneous, though separated from each other by the barrier of the Grampian Mountains, which formed an effectual boundary between two ichthyic faunas" (**71**, 364, 365).

Deposition in the Sea. To certain geologists it will appear that I am wasting paper in setting forth a theory which has as its thesis the deposition of the Old Red sandstone in the sea, and that it is a further useless expenditure of ink and of the reader's time for me to voice the objections to such a theory. Indeed, I would agree with anyone who raised such a protest were it not for the deplorable fact that there are still not a few geologists who claim that this much-talked-of red sandstone was deposited in the sea, and further that other sandstones with similar striking lithological and faunal characteristics could have been formed nowhere else but in that region where all sediments have been deposited since the world began, namely, in the littoral zone of the sea.

The chief advocates for the theory of marine deposition are Macnair and Reid who brought out two papers in the *Geological Magazine* for 1896, one entitled "On the Physical Conditions under which the Old Red Sandstone of Scotland Was Deposited" (**159**), and the other "Palaeontological Considerations on the Old Red Sandstone of Scotland," (**160**), in which they sought to prove that physical, stratigraphical and palaeontological evidence all pointed to the marine origin of the Old Red. In a few words their interpretation may be summarized: in pre-Devonic time there was a large land-mass to the northwest of Scotland which supplied the material for much of the marine deposits during Cambric, Ordovicic and Siluric time. At the end of the Siluric the sea began to transgress across Scotland and the land-mass was at the same time depressed until by sinking and by marine erosion the whole area disappeared beneath the sea and the

Upper Old Red sandstone was deposited over the whole of Scotland. In the words of the two authors mentioned above, "The great mass of this mountain chain, then, must have lain to the northwest of the present Old Red Sandstone area, and we now proceed to show how after this long period of upheaval the mountain mass once more began to sink below the level of the sea, and that gradually the waters of the Old Red Sandstone sea levelled it down to the very core" (**159**, 109). They consider that all of the deposits were made along shore, but they are then confronted by the problem of the lack of molluscs and other typical marine forms. This absence they thus account for: "The solution of the problem rather lies in the fact that the presence of peroxide of iron in these rocks is inimical to the preservation of fossils with a calcareous test, and·that more especially in the case of sandstones, which even when composed of pure sand are well known to be a bad medium for the preservation of molluscan and other similar organic remains" (**159**, 116).

Objections to Lake and Marine Theories. Each of the two theories given can explain some facts which the other cannot; but, on the other hand, each has very serious faults due in some cases to incorrect observations, in others to the acceptance of prevalent ideas and in others to unjustifiable deductions. Both theories contain elements of truth, but both are open to many objections. These fall into two groups: (1) Physical, (2) Faunal.

(1) *Physical.* (a) Red color. Within the last twenty years students of sedimentation have clearly shown that it is impossible for a widespread and thick series of red clastic deposits to be laid down in the sea. The red color, as is well known, is due to the dehydration of sediments which were thoroughly oxidized at the time of deposition. Such oxidation cannot take place under water, but only during exposure to the air. It is not to be supposed that the beds were red when deposited, but that only after dehydration had taken place by the lapse of a long period of time, or through the effect of heat from the interior of the earth, or by pressure was the red color taken on. Of course, certain red beds may receive their final working over under water, but such deposits will be of limited thickness and areal extent. For instance, the Bays sandstone (Upper Ordovicic) of Tennessee, Virginia and adjoining regions is a red calcareous sandstone with a maximum thickness of 1500 feet. Throughout most of the formation organic remains are absent, but in the lower beds marine fossils occur abundantly in a few layers of the red sandstones. These

fossils are all mollusca and brachiopods, are numerous and well-preserved, a fact not compatible with the reasoning of Macnair and Reid. As has been fully explained by Grabau, the main mass of the Bays represents an alluvial fan spread out on the land and having its western and southernmost margins extending into the sea. Thus it was possible for some of the highly oxidized sands to be carried out to sea, where they were deposited and where marine fossils were entombed with them. There is, therefore, nothing inherent in potential red deposits to prevent marine shells from being preserved in them; the difficulty lies in the fact that great thicknesses of potential red beds can not be deposited under conditions where it is possible for marine animals to leave their record, because such deposits must be formed on the land. As for the inimical effects of iron peroxide, it need only be stated that the reddest of deposits contain only a small amount of iron[14] and that it is not the amount but the fineness and perfection of dissemination of the iron that are responsible for the color (Grabau, **87,** 621). That sandstones made up of grains of pure silica are bad media for the preservation of molluscs is easily disproven, for one need only recall such highly fossiliferous formations as the Oriskany sandstone and the Schoharie grit of the Devonic of New York, or the Miocenic sands and conglomerates of the Vienna Basin. The reason why so many sandstones are unfossiliferous is generally that they were deposited as terrestrial sediments either fluviatile or eolian.

(b) Marine denudation. A second argument advanced by Macnair and Reid is based upon the assumption that the erosion of the Siluric rocks in the Highlands of Scotland was due to marine denudation and upon faulty observations at certain localities. They argue "The marine denudation of the Silurian rocks of the Highlands of Scotland is not in dispute, but Ramsay and Geikie have assumed a subsequent lake or fresh-water denudation." The conformable deposition, however "of the Old Red Sandstone upon the preceding Upper Silurian deposits in the counties of Edinburgh and Lanark, the Welsh area, and in the St. Lawrence basin, precludes any such idea; for from the base of the Upper Silurian to the top of the Lower Old Red sandstone the sequence of these deposits is unbroken. It therefore follows that the denudation of the rocks of the Highland area being marine, the equivalent deposits occurring in the Upper Silurian and Lower

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[14] The bright red Vernon shale (Salinan) has shown on analysis only 2.25 per cent of ferric oxide and 0.75 per cent of ferrous oxide.

Old Red Sandstone are equally marine "(**160**, 221). The chief objections to this theory of marine denudation continuing from the beginning of Upper Siluric to the end of Lower Devonic time, fall into three groups: (1) *Tectonic.* The tectonic relations between the Old Red sandstone and the underlying rocks show that there was profound folding at the end of the Siluric, followed by a long period of erosion before the earliest Old Red sediments were deposited; therefore the two series are not conformable as claimed by Macnair and Reid. (See further p. 173 above). (2) *Lithologic.* (See below, sections (d), p. 182, and (1), (2), (3) on p. 189). (3) *Faunal.* (See below, section (b), p. 191).

(c) Salt indicative of marine deposition. The argument that the presence of a salt-bearing stratum in the Old Red at one locality is undoubted evidence of the marine origin of that bed, is of no value unless supported by critical data on the chemical composition of the salt and associated salts if any are present, and on the organic content. Too much is now known concerning the continental origin of many and perhaps the larger number of past and present salt deposits for anyone to claim that the sea was always or even commonly the immediate source of the material. Macnair and Reid would make the presence of the salt band an *a priori* reason for its marine origin, for they say: "We find in the Moray Firth area a large stratum of yellow *saliferous* sandstone, interbedded with shales containing remains of Old Red sandstone fishes . . . . and we think that but one conclusion alone can be drawn therefrom—that the formation and its contained fish remains were marine" (**160**, 221). This type of reasoning is delightfully ingenuous and one that is met with frequently; while the authors do not explicitly state any reason why the salt is marine, the reader yet receives the impression that the presence of fish remains carries a strong presumption, and thus we have the pleasing circle: "The salt is marine because associated with fish, and the fish are marine because found in bands interbedded with salt-bearing sandstones." This whole argument would fall to the ground were anyone to show that the fish were fluviatile, or that the salt could have some other origin.

(d) Thickness of deposits. The recurrence in the same place of thick boulder and pebble conglomerates interbedded with sandstone and shales, all being dominantly red and showing a complete absence of unequivocal marine fossils such as brachiopods, molluscs, crinoids, and trilobites, and amounting in thickness to many thousands of feet proves conclusively that the beds could not have been deposited by an advancing sea, as contended by Macnair and Reid, nor yet in a lake, as Geikie holds. It is not even necessary to point to the red color or to the absence of marine fossils; the thickness and coarseness of the deposits absolutely precludes the possibility of their having been formed in the sea. Macnair and Reid hold that the sea transgressed from the south to the north, but in that case, while there might well have been a basal conglomerate a few feet thick, this would inevitably have been succeeded vertically by finer deposits, sands at first and then muds or limestones as the water became deeper, and the zone of coarse near-shore deposits would have advanced *pari passu* with the transgression of the sea. Thus it would have been impossible for coarse material to have been deposited in southern Scotland in the Upper Devonic when the sea shore stood two hundred miles to the northwest. Greater obstacles arise if we attempt to have these deposits formed in lakes or epicontinental seas. In Forfarshire, the position of "Lake Caledonia," the estimated thickness given by Hickling is 12,500 feet, including the volcanics, or considerably over 10,000 feet of clastic deposits; in Caithness Geikie estimates the series which he supposed to have been contemporaneously deposited in "Lake Orcadie" at 16,200 feet. These two lakes were separated by the Crystalline Highlands, a strip of land about 90 miles broad, which apparently supplied the sediments for Lake Orcadie. The waves of this great lake, which is estimated to have had at its maximum a surface of about 48,000 square miles, cut back into this old mountain chain which was at the same time being denuded by the rivers which brought their loads into the lake. In its maximum developed Lake Orcadie extended from Nairn to the Shetland Islands, the Orkneys representing a sublacustrine rise. The cross section made by Geikie is here reproduced in order to show his interpretation (fig. 18). It is at once apparent that there was not enough dry land to supply the thousands of feet of flagstones making up the Caithness series. It is even more difficult to surmise whence came

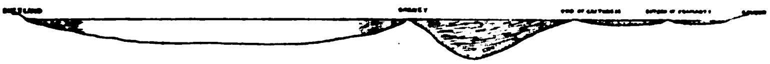

FIG. 18. SECTION TO EXPLAIN THE DEPOSITION OF THE OLD RED SANDSTONE IN THE NORTH OF SCOTLAND
(After Geikie)

the material which filled up the mid-Scottish basin or "Lake Caledonia," for it was hemmed in on the west by a narrow ring of hills separating it from "Lake Lorne" in North Argylshire, and on the south by hills along an east-west line through the Firth of Forth, and on the north by the Highlands which were the source of the 16,000 feet of sediments deposited in Lake Orcadie, while to the east the sea covered France. The only other source would be a mountain chain in the present English Channel, but the objections to this are obvious. A natural question that arises often in reading Geikie's monograph, and one which Macnair and Reid most pertinently ask is how outliers of conglomerates on the tops of high mountains, in the very regions which were supposed to have been lake barriers, are to be accounted for. Geikie has proposed that perhaps they represent old fiord-like indentations in the shoreline. This explanation will not serve, however, when such outliers are found on what must have been the very centre of the ridge between Lakes Orcadie and Caledonia, such, for instance, as Macnair and Reid mention at Mealfourvonie just north of Loch Ness in Inverness where an outlier is found 2284 feet above sea-level, and at Tomintoul in Banff, and Rhynie in Aberdeen. The outliers in all parts of Scotland indicate that the deposit was essentially continuous, though varying in lithological character and origin from place to place.

(e) Structural features. The cross-bedding, ripple marks, and other structural features that are cited by some authors as indicative of marine littoral conditions of sedimentation, by others as lacustrine littoral, will be considered below under the third theory of the origin of the Old Red sandstone (p. 189).

(2) *Faunal.* Attention should be called to certain erroneous lines of argument that have been used and which fall down because based on false premises. For instance, it is impossible to prove that the Old Red sandstone eurypterids were marine by saying that the Siluric ones were and that therefore the Devonic ones of the same genera must also be. First it must be proved that the Siluric eurypterids were marine. To quote once more from Macnair and Reid: "We have . . . . seen no reason assigned why Eurypterids and Placoderms of the same genera, which are marine in the late Upper Silurian, and fishes of the same genera and species which are equally marine in the Devonian of Russia and Central Europe, as well as in the Devonian of North America, should be termed equivocally marine in the Old Red sandstone" (**160,** 219). It may be remarked that the

Devonic fishes of North America here referred to have been shown, from their occurrence and distribution, to be mostly if not entirely fluviatile (Grabau **87, 88**).

Macnair and Reid have with great justification brought forward many objections to the "Lake theory" advocated by Geikie, but their logic fails them when they contend that because the Old Red fish and eurypterids could not have been lacustrine forms, therefore they must have been marine.

The river origin seems never to have occurred to these two writers, or else if it did they considered that the same objections were open to it as to the lake origin. One of the arguments which they advance against the lake theory is the difficulty of the origin and distribution of the fish and eurypterids. They argue thus: these forms were present in the Siluric and so it is not strange that they should occur also in the Devonic; "but of the genera Osteolepis, Dipteris, Glyptolepis, and other fishes of the Old Red Sandstone no undoubted plates or scales occur in the preceding formation. The question therefore arises, whence came these highly organized fishes of the Old Red Sandstone? More especially, from what fresh-water region did they migrate? Not only so, but as the same genera of fishes occur in the Devonian of North America and the St. Lawrence basin, we have an equal right to know by what fresh-water pathway of distribution they were enabled to migrate some 3000 miles between one point and another" (**160,** 218, 219). But surely such facts of distribution should not be distressing; many a case could be cited in the recent fresh-water fish fauna of the same genera occurring more than 3000 miles apart, and with perhaps no related genera in the intervening area. One may mention the case of the genus Umbra, a form so peculiar as to be made the type of a family in which are only two species, these being most closely allied, and yet one occurs in the rivers of the Atlantic states of North America and the other in the Danube system, some thousands of miles distant. Even more remarkable is the genus Scaphirhynchus among the sturgeons, which likewise has two species: one in the Mississippi system, the other in Central Asia. In the same family is the genus Polyodon, with two species only, one in the Mississippi, the other in the Yangtse-kiang. But one need not confine the illustrations to *genera* which are identical in distant regions; *species* offer even more surprising examples. *Perca fluviatilis*, *Gastrosteus pungitius*, *Lota vulgaris*, *Salmo salar*, and many others might be mentioned, inhabiting both the rivers of eastern North America and of Europe. For an extended discussion on migration the reader is referred to chapter V on that subject below, especially pp. 203–7. These illustrations will suffice to show that fresh-water forms can often migrate for several thousand miles, and that through river distribution even the same species may occur in regions widely separated. It may here be remarked that distance is of less significance than time available for migration (see below, pp. 208 *et seq.*).

SUMMARY. The objections to the marine and lacustrine theories of deposition for the Old Red may be reduced to the single criticism that they are out of date. The theories were helpful attempts toward the solution of one of the big problems in stratigraphy, but in their formulation and working out, their authors naturally followed the ideas which were accepted as correct twenty years ago; that some of these should have been found to need revision is only an evidence of the progress of science. The study of sedimentation is a branch of geology which is even yet not receiving the attention due it, but, nevertheless, the students of lithogenesis are steadily increasing, and there is more being said and written today about the work of the wind and of rivers in the geological past than there was a dozen years ago.

THEORY OF FLUVIATILE DEPOSITION. The conditions up to the beginning of Old Red sandstone time have already been outlined and it was shown that there was a progressive retreat of the sea to the south, leaving all of Scotland and most of England a region of dry land subject to the subaërial forces of denudation, the greatest of which are the winds and the rivers. The rivers cutting down into the newly elevated continent carried great quantities of detritus toward the sea. But these were not the rivers of a pluvial climate. They were rather the torrents which carried off the waters from occasional heavy rains such as occur in semi-arid regions. That the climate must have been relatively dry is indicated by the thickness and great areal extent of the Old Red Sandstone, for, as was explained, these deposits must have been thoroughly oxidized at the time of their deposition in order that they might be potentially red. In post-Devonic time, either by age, heat or pressure, those oxidized deposits became red through dehydration. The climate, then, was semi-arid and the rivers of the nature of torrents which could transport vast quantities of material, but which would in most cases drop that material before reaching the sea. This would be brought about because the streams would soon lose their supply of water, for the rains were only periodic and even the water which was collected into streams would be lost by evaporation or by sinking into the ground. Great alluvial fans were spread out, consisting of coarse conglomerates near the source of supply and of sands farther away. During those periods when the infrequent but heavy rains fell, playa lakes undoubtedly were formed, similar to those known to be characteristic in present semi-arid regions which have periodically inundated river flood plains. Evidence is not wanting that just such water bodies did form, for Geikie has called attention to certain characteristics in the Thurso flags which admit of no other interpretation. Along the northern coast of Caithness from Castletown to Thurso, a distance of some seven miles along the beach, these flagstones are exposed in great sheets. They consist of "fissile, calcareous, grey, hard flagstones, green, gray and brown calcareous (and frequently bituminous) shales, with thin bands of calcareous gritty sandstone and argillaceous limestone ('calmy limestone'), seldom more than a few inches in thickness. . . . . Even when split into smooth sheets an inch or less in thickness, these hard, tough layers show on their yellow, weathered edges successive paper-like but mutually adherent laminae. . . . . "

A second feature is "the extraordinary abundance of ripple-marked surfaces and sun-cracks. Though these markings abound also in the lower flagstone group, it is here that they attain their greatest development. Surfaces of flagstone or shale, many square yards in extent, are profusely covered with fine ripple lines as sharply preserved as if only today imprinted on the soft sediment. In many places every successive stratum or leaf of rock is thus marked, so that several distinct rippled surfaces may be counted in the thickness of a few inches of rock. It is likewise observable that the rippling is generally close-set, sometimes not exceeding an inch in breadth from crest to crest of the ridges."

Mud-cracks form a third important structure. Geikie says: "More abundant and admirable illustrations of sun-cracks could hardly be found than occur along the coast. Broad, gently-inclined sheets of rock again and again present themselves to view so covered with reticulations as to look like tessellated pavements. It may be noticed that the cracks not infrequently descend through many of the fine laminæ of deposit for a depth of 5 or 6 inches with occasionally a breadth of 3 or 4 inches. The material filling up the interstices abounds with small, occasionally curved pieces of shale. These may, no doubt, be regarded as portions of the upper muddy layer which cracked off and curled up during desiccation, as may often be observed on dried-up pools at the present time. Some pittings, occasionally seen on the sun-cracked surfaces, may perhaps represent rain-drops" (**71**, 392, 393).

Such characteristics as those just cited have been used by Geikie as proof of the lake shore origin of the beds and by other writers as indicative of their formation in mud-flats along the sea coast. Were it not that such interpretations are offered by the majority of geologists it would be unnecessary to dwell upon the unequivocal interior continental origin of these features. That mud-cracks should be formed over wide areas indicates beyond a doubt the presence of a large body of very shallow water which completely evaporated, leaving the whole surface exposed to the air. Not only that, but the exposure must have been long for the cracks to be 5 or 6 inches deep and occasionally 3 or 4 inches wide. Professors Grabau and Barrell have discussed this subject of ripple marks and sun-cracks over wide areas in such a convincing and logical manner that it need not be taken up in detail here. In his *Principles of Stratigraphy* Professor Grabau cites the case of the great playa in the Black Rock Desert, Nevada, which forms in a few minutes and covers an area of from 450 to 500 square miles and yet is seldom over a few inches in depth. Russell has described this lake and records that in a few days all of the water may dry up leaving the surface cracked in all directions. "The lake beds then have a striking resemblance to tesselated pavements. . . . . "—the very words used by Geikie in describing the Old Red flagstones! Grabau says: "Taking the areas of mud-crack formation in the order of their magnitude, the playa surface would probably stand first. Here the entire surface for hundreds of square miles becomes mud-cracked, often to considerable depth, on the complete drying up of the temporary playa lake. Here, too, the conditions for the preservation are most favorable. Not only is the exposure a long one, often the greater part of the year, or for many years, and for much of the time to intense heat, but the chances of proper burial are much greater. Wandering sand dunes may thus preserve the record, dust deposits may fill the fissures, or, at the next flood, sands or muds may be swept into them. In fact, the playa or takyr seems to be the ideal surface for mud-crack record, and one is tempted to refer most mud-cracked strata to such an origin. Certainly where fossil mud-cracks penetrate a formation to the depth of 10 feet, as is the case in the Upper Shinarump (Triassic) shales of Utah, it is difficult to believe that they could be formed under other conditions than those permitting prolonged exposure such as is found only in the playas of the desert, where ten years or more may elapse between rainfalls. . . . . If the playa lake exists for some time it may become stocked with certain forms of organisms, especially types whose eggs or larvæ can be transported by wind or by birds. The small crustaceans Estheria, Daphnia, and Cypris are characteristic of desert lakes, the first being found in ponds which are dry for eleven successive months" (Grabau, **87,** 707, 603). The nature of the organisms characteristic of such playa lakes is exceedingly interesting in view of the fact that Geikie adds to his description of the lithological characters of the beds in question the following statement: "Fragments of fish and coprolite are scattered abundantly through most of the flagstones. Some of the calcareous shales are full of Estheria, while traces of plants occur in great numbers, though generally in a somewhat macerated condition" (**71,** 393). The close correspondence between the description of modern playa deposits and the Caithness flag portion of the Old Red Sandstone series leaves no reasonable doubt that the latter formation was the result of inland drainage in a semi-arid or desert region.

The detailed characteristics of a single series of beds in the Old Red have been taken as an example illustrating the conditions which prevailed, but attention need not be confined to any single part of the formation, for Goodchild has found evidence in all of the divisions of the Old Red to show that desert conditions prevailed throughout all the Devonic wherever this type of deposition obtained. In order not to burden the discussion with a too lengthy description of all of the features indicating desert or at least continental origin for these deposits I shall give a list setting forth the facts already cited and certain additional ones.

Summary of Evidence for Fluviatile Deposits. (a) Lithogenesis. (1) The presence of finely stratified, rippled and sun-cracked flags over an area of many square miles, and at successive horizons, the sun-cracks penetrating to a depth of five or six inches and being at times three or four inches wide, indicates playas or at least broad river flood plain conditions. These features have been noted by Geikie in the Thurso flags (**71,** 392, 393).

(2) The presence of clay galls in the deep interstices between the sun-cracked prismatic layers in the Thurso flags indicates exposure of clayey surfaces to the air long enough for flakes to be curled up and blown into the cracks. Such a feature might characterize any sun-cracked area, but the depth of the cracks as cited in (1) indicates a playa or a river flood plain.

(3) The basal conglomerate of the Orcadian series has characteristics pointing to the fact that it is made up of material derived from the *disintegrated* but not decomposed underlying rocks, thus indicating dry climatic conditions during its formation. The conglomerate is too thick to represent the basal conglomerate formed by an advancing sea, even if other characteristics did not preclude the marine origin. In detail the characteristics are as follows: (a) "The blocks vary in size up to as much as a yard, or even more, in length, and consist of gneiss, pink granite, quartz-porphyry, quartz-rock, mica-schist, and other crystalline rocks, with abundance of pink cleavable orthoclase derived from the underlying gneiss" (**71**,375). In the Caledonian series the blocks are even larger, Hickling having recorded them up to 8 feet in diameter. (b) In every case the underlying rock from which the conglomerate boulders were derived can be found not far away. "Near the granite they (the boulders) are made up in great measure of granitic debris. Round the quartz rock they are largely composed of that material. The existence of the well-veined orthoclase gneiss is indicated some distance before the underlying rock is actually seen by the abundant fragments of beautifully cleavable pink felspar in the conglomerates" (**71**, 370). (c) In both of the quotations just given reference is made to the abundant presence of fresh pink orthoclase. Goodchild has likewise referred to the arkoses with unweathered feldspar fragments (**80**, 219), and has pointed out that they indicate disintegration under semi-arid or desert conditions. (d) The basal conglomerate is too thick to be of any other than fluviatile, more especially torrential origin. For instance at Sarclet, about five miles south of Wick, Caithness, a great mass, 250 to 300 feet high, rises from the sea, the base not being visible. Here "the matrix, red in colour, and less strongly felspathic than towards the south, contains large and usually rather well water-worn fragments of quartz-rock, granite, felspar, porphyry, and red sandstone" (**71**, 376). On no sea or lake beach is a large boulder conglomerate 250 feet thick ever formed by the action of waves.

Along an open coast exposed to the full force of the waves great boulders may indeed pile up, but they will be in a very narrow strip at the foot of the cliffs and will rapidly decrease in size until within but a few feet from shore no large ones will be found and those which do occur will be in only a thin layer wedging out seaward. Moreover, a boulder conglomerate formed along a seacoast would almost certainly be fossiliferous, as I shall point out below. Such a conglomerate might, however, easily be piled up by the waters of the swift and powerful torrents which periodically occur in desert regions. In large basins of inland drainage the rivers flowing down the enclosing mountains bring in great quantities of debris which is coarse and bouldery near the mountains and finer further out. Davis records that "A great part of Persia consists of large basins enclosed by mountains and without outlet to the sea. Long waste slopes stretch forward five or ten miles with a descent of 1000 to 2000 feet, stony near the mountain flanks and gradually becoming finer textured and more nearly level. The central depressions are absolute deserts of drifting sands with occasional saline lakes or marshes" (**87**, quoted from Davis, **50**, 588).

(b) Faunal. Throughout the Old Red sandstone of Great Britain and the continent, typical marine organisms are absent except where this facies interfingers with the Devonic marine facies. The types of life represented in this whole series are few and yet of exceeding interest, since they are among the earliest of land forms, such as scorpions, insects, freshwater crustacea, fish and eurypterids, while the flora, though much poorer than that from the Gaspé sandstone of New Brunswick, yet shows the presence of ferns, coniferous trees and vascular cryptogams. The Caledonian Old Red, which is largely conglomeratic, has yielded comparatively few fossil remains, but in the Pterygotus-or Carmylie- sandstones of Forfar, *Pterygotus anglicus* has been found associated with *Parka decipiens* and at a higher horizon Cephalaspis and Pteraspis occur, and still higher the Acanthodian beds of Turin with a good fish fauna as well as *Pterygotus anglicus* and *Stylonurus ensiformis*. Thus, in the Caledonian Old Red, a series 12,500 feet or more in thickness, the fish and eurypterids are the only abundant organisms. This single faunal fact would be sufficient, even though all other types of evidence were wanting, to make me say that those two groups of organisms lived in the rivers (see criteria, p. 77 above). In the Orcadian the fauna is more varied. Traquair, who has made such a careful study of the ichthology of the Old Red Sandstone of Great Britain, has established the following fish zones in the Caithness area (**272**):

John O'Groats	Tristichopterus alatus Egert. Microbrachius dicki Traq.
Thurso	Coccosteus minor H. Miller Thursius pholidotus Traq. Osteolepis microlepidotus Pander
Achanarras	Pterichthys, 3 species Cheirolepis trailli, Ag. Osteolepis macrolepidotus Ag.

This fish fauna is very different from that to the south of the Grampians in Forfarshire, there being no species in common between the two areas and only two genera, Mesacanthus and Cephalaspis, the latter being represented in Caithness by only a single specimen.[15] From this division no eurypterids have been reported.

In Caithness and in the Orkneys and Shetland isles has been found a phyllopod crustacean of a genus which at present lives in rivers and fresh water lakes and playas, namely, Estheria. T. Rupert Jones has described the species *E. murchisonia*, which is abundant in a "dark grey, tough, fine-grained, sandy flagstone, slightly micaceous, somewhat varying in tint and hardness. . . . . Great numbers of the valves are spread over large surfaces of the flagstone, sometimes scattered sparsely, sometimes congregated in groups, forming films between the layers of fissile stone" (**191**, 405). Murchison says of this species: "It occurs in certain localities in such numbers as to form layers an inch or two thick, entirely made up of the thin carapaces" (**191**, 404).

The Old Red sandstone of Lorne has yielded, besides *Pterygotus anglicus* remains, two species of chilognathous myriopods, *Campecaris forfarensis* (Page) and *Archidesmus* sp. described by Peach (**214**, 83). These are among the earliest myriopods yet known and suggest that the beds in which they were found were formed on land, for if the myriopods had been transported far they would have been destroyed. Moreover, since they had not hard parts to be preserved, they must have been buried quickly. A playa would be the ideal place for their burial, but I do not know enough about the beds in which they were found to state that they were formed in a playa. Macconochie has

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[15] The significance of this fauna has already been discussed in chapter III, p. 92, and the other aspects will be considered below, p. 247, *et seq.*

discovered in these beds plant remains related to Psilophyton, and a fish which Traquair describes as *Cephalaspis lornensis* (Macconochie 157, Traquair 273).

Geikie calls our attention to what is believed to be "the oldest lacustrine or fluviatile mollusk yet known, *Amnigenia* (*Anodonta*, *Archanodon*) *jukesii*. This shell has been found in the Upper Old Red Sandstone of Ireland and England, associated with land-plants, (*Archaeopteris*, *Sphenopteris*, *Bothrodendron*, *Ulodendron*, *Stigmaria Calamites*) fishes (Coccosteus) and arthropods (Eurypterus).

12. MISCELLANEOUS OCCURRENCES

We have now completed the discussion of the significance of the eleven most important eurypterid faunas, the ones which it has seemed to the writer offered the most material from which to draw deductions. In addition there is a certain group of occurrences which appear to be able to throw little light upon the determination of the habitat, and they have not been discussed so far, for, if from the best material which we have at hand it can be proved that the eurypterids lived in the rivers from the very beginning of their history, then we need be no more distressed at finding a fragment among marine remains than we are when we find a single leaf or piece of wood associated with brachiopods and molluscs. But, lest the advocates of the early marine habitat of the eurypterids should complain that I pass over lightly the very cases which seem to prove conclusively to them that their view is correct, I shall take up those cases briefly and show wherein they do not prove what they are supposed to; but rather if of any weight at all, indicate that the eurypterids did not always live where their remains were entombed. These remaining instances, then, fall into three groups.

(1) The presence of a single eurypterid fragment or perhaps two or three fragments associated in the same stratum with a typical, well preserved, marine fauna.

(2) The presence of a single eurypterid fragment or complete individual in a stratum barren of other fossils, but immediately preceded and succeeded by strata carrying marine fossils.

(3) The presence of quite a number of fragments in scattered occurrence, but associated intimately with a typical marine fauna.

To the first group belong the following:

Echinognathus clevelandi, Utica shale, Upper Ordovicic.

The eurypterid fauna of Condroz, Upper Devonic of Belgium.
Pterygotus problematicus, occurrence doubtful in Aymestry limestone.
Eurypterus punctatus fragments, Wenlock limestone, England.

To the second belong:

Strabops thacheri, Potosi limestone, Upper Cambric or Lower Ordovicic.
Eurypterus prominens, Clinton.
E. boylii, Guelph.
E. microphthalmus, Manlius; Monroe.
Pterygotus problematicus, May Hill sandstone, Llandovery.
Eurypterus sp. Wenlock (of Southern Belt, Scotland).
Eurypterus sp. Wenlock (Girvan area, Scotland).
Pterygotus australis. Upper Siluric of Australia (Information insufficient, may belong to group 1).
Pterygotus osiliensis, Pterygotus marl of Gotland.

To the third group belong:

The Siluric fauna of Bohemia.
The Lockport fauna of Ontario.
The Siluric fauna of Podolia and Galicia probably belongs here.
Pterygotus sp. Siemiradzki, Middle Devonic of Galicia.

The lines of argument for the above occurrences have been stated from time to time, but are scattered throughout the paper. They may be brought together here for reference since so many of the cases are subject to the same arguments. In chapter III the criteria for recognizing the various types of habitats in the past were fully discussed, and will now be of great help in establishing the nature of the habitat indicated by the various eurypterid occurrences given in the three lists above. In the light of the arguments that have gone before, and especially of the discussion on habitats, the following truths may be considered as self-evident or as easily demonstrable.

1. The occurrence of a single fragment, or of two or three fragments, or of a single complete eurypterid in a formation where it is associated either intimately in the same stratum or closely in adjoining strata with a typical marine fauna, as defined on p. 76, cannot be considered as proof that the eurypterid remains are a part of the marine fauna, for the following reasons: (a) it is impossible to explain how any group of marine organisms could have their remains so completely destroyed that but a single fragment should be left; such is

never the case with other groups of marine organisms and it is not logical to suppose that the eurypterids should in so many instances have suffered complete annihilation, leaving only one fragment behind to show that they had lived in the sea of that period. It has been suggested that the eurypterids, like modern crabs and horseshoe crabs, were cannibalistic, not only devouring living members of their own family, but also the molted exoskeletons, in this way destroying most of the hard parts which might otherwise have been preserved. This is an ingenious explanation to account for the fragmentary condition of the eurypterids so frequently observed, but when we attempt to explain similarly the appearance in the rocks at a given horizon, of only one fragment, the result is a *reductio ad absurdum*. For unless we are to believe in a miraculous mutual devouring, such as that which took place between the "Gingham Dog and the Calico Cat" as so vividly described by Eugene Field, we would still expect survivors from the feast. Are we to let imagination run wild and to picture to ourselves a fierce struggle in those ancient seas between the members of the eurypterid family, a struggle which caused the destruction of young and old alike, friends, neighbors, and relatives, until a single maimed, but victorious individual remained? But, if we go so far, we must look at the last scene, must gaze upon the painful sight of that last survivor, demented by his orgies, tearing his own limbs apart and devouring them until—well, we would expect that his jaws and ectognaths would have been the final things to remain, but strangely in the Utica sea it was a claw which remained. It is painful to think of the destruction of the young merostomes in these periodic holocausts, that whole faunas should have perished leaving no descendants, and of the infinite labor Nature must have had to create anew genera and species for succeeding seas! Yet, when the early Palaeozoic periods were past these frightful scenes of wholesale destructon gave way to gentler, more pacific modes of life, so that in the Upper Siluric in central and western New York and on the Island of Oesel we find indications from the fossils that the eurypterids lived amicably to a ripe old age, dying a natural and peaceful death and enjoying a decent and fitting burial in the fine muds of those times. Thus we see again the steady progress in evolution from the early days of barbarism to the later ones of communal altruism. (b) It is impossible to explain the occurrence of one well preserved eurypterid with no other associates, such for instance as *E. prominens;* for, if the conditions for perfect preservation obtained, then the rest of the eurypterid fauna should have been preserved. (c) If we are to consider that a single fragment of a eurypterid when found in marine strata proves that the eurypterid lived in the sea, then, provided no other proof existed to the contrary, insects, land shells, leaves, logs, spiders, scorpions and other land forms which are often floated or blown out to sea and which are found today thousands of miles from land, and have often been met with in the rocks associated with marine forms would also be considered as inhabitants of the sea. Since the reasoning given on pp. 93-193 has shown that the most significant and important occurrences of the eurypterids point to a fluviatile habitat, then the single special cases should not be cited as proof to the contrary. It is just as if we were to say that, in spite of the many abundant, well preserved floras of the order Fagales known throughout the world in continental beds from the Cretacic to the present, we were forced to conclude that birch and oak trees have always constituted part of the open marine flora, because in some dredging operations today an oak trunk and a number of birch leaves were hauled up one thousand miles from shore. Specific instances of anomalous occurrences have been cited on p. 67, but I shall give one further illustration here to show how little association may mean.

The Upper Devonic sandstones of Condroz Belgium with an aggregate thickness of 22 m., constitute the sandy phase of the Famennian shales of the lower part of the Upper Devonic. They are of interest because of the mixed marine fauna and terrestrial flora found intermingled in them; brachiopods, pelecypods, land forms including ferns, and the fish characteristic of the upper Old Red of Scotland are found associated, and the American genus Dictyospongia also occurs in this sandstone. Since at least part of the fauna is marine, and the flora is terrestrial, the eurypterids might be interpreted either as marine or fresh water forms; but inasmuch as only a few fragments have been found, the more rational interpretation would seem to be that the organisms did not live in the sea. This is further borne out by the fact that as the Upper Devonic beds are traced to the south into Germany they become pure marine limestones, in which no eurypterids have been found, but traced to the northwest they merge into the Old Red sandstone of England and Scotland which contains eurypterids and fresh water fishes. The deposits in Belgium, then, mark the meeting-place of the marine and terrestrial waters as the sea encroached from the south upon the Upper Old Red shore, and for this reason it is impossible from a study of the fauna, flora and sediments of that region alone to arrive at any conclusion as to the habitat of one group of the organisms whose remains are found there. If, for instance, we had no information from other sources regarding the ecology of the pelecypods, it would not be safe to infer that they were marine organisms because associated with brachiopods, nor would it, on the other hand, be fair to assume that they were terrestrial because ferns were embedded in the same strata. The same may be said for the eurypterids; nothing regarding their habitat can be inferred from their appearance in such beds as these sandstones with a commingled marine and terrestrial assemblage of organic remains. In some cases it is possible to take account of more factors, such as the relative perfection of preservation of the various groups of organisms when one, perhaps, shows evidences of transporation and consequent maceration, or again, the relative scarcity or abundance of species and individuals. In the instance of the sandstones of Condroz, I think that it is justifiable to attach importance to the sparse and fragmentary condition of the eurypterids as compared with the abundance and good condition of the other organic remains, and to conclude that probably the merostomes did not live in the region where their fragments finally came to rest.

2. The truth of the thesis of the above paragraphs being accepted, it must be acknowledged *a fortiori* that a single fragment or even a complete individual in a stratum in which occur no remains of typical marine organisms, intercalated in strata which do, is not the slightest proof that the eurypterid was an inhabitant of the sea.

I may here, as an illustration, give an account of the occurrence of *Strabops thacheri*, the only known eurypterid from the Upper Cambric or Lower Ordovicic Potosi Limestone of Missouri. In the section near Flat River, St. François Co., Missouri, given by Nason, the Potosi formation is represented as resting disconformably upon the Bonne Terre or St. Joseph limestone of uncertain Cambric age, but probably at least Middle if not Upper Cambric. At the base of the Potosi is an edgewise conglomerate extending upward for about 6½ feet and followed by 100 feet of conglomerates and interbedded slates, the latter carrying several species of trilobites, brachiopods and an occasional *Hyolithes primordialis*. As was stated on p. 13, Beecher, who identified the fossils collected by Nason and who described the one eurypterid found, did not and perhaps could not state in just which layer Strabops occurred and whether it was found directly associated with the marine forms. From a study of the material in the Palaeontological Museum at Columbia University, I have found that the rock in which Strabops occurs is not of the same lithological character as is that in which the other fossils occur. The slab on which the counterpart of Strabops rests is roughly 3 x 9 x 12 inches in dimensions and contains no other organic remains. The limestone containing the trilobites is somewhat finer grained, differing little in color, but being made up of numerous cephala, pygidia and fragments of several genera of trilobites. The difference in faunal character between the two rocks is pronounced. The slab containing Strabops was not collected by the same person nor at the same time as were the other fossils, so that exact data probably will never be obtained. However, the precise association is of slight import. The alternation of limestone conglomerates and shales in the lower Potosi series indicates near-shore conditions of sedimentation, and the occurrence of the single specimen of a eurypterid, far from pointing to a marine habitat for this one individual, militates very strongly against such a mode of life. In all cases the occurrence of a single individual is one of the strong arguments against the assumption that the individual belongs to the fauna of the bed in which it is found. It is far more logical to assume that it has been brought there by some accident, for in Nature we do not find single individuals of any kind of animal in a region far removed from that occupied by other members of its family. Again, the only way to account for this occurrence is to assume that these eurypterids were living in the rivers of that time, and that this individual happened to be carried out into the shallow sea in which the Potosi limestone was being deposited. That the sea was shallow is indicated by the fine stratification of the rock as well as the paucity of the organic remains which are insufficient to have furnished the lime of which the formation is composed. This limestone like others of its kind seems to have been formed from the calcareous sand and mud carried by surcharged rivers coming from limestone regions into shallow sea-border basins.

The merostomes of the Stephen shale of British Columbia are not now recognized as eurypterids, but belong to a distinct order, that of the Limulava Walcott (Clarke and Ruedemann **39**, 410). Hence their association with marine organisms may be disregarded.

3. It may not be quite so clear that the occurrence of a fairly large fauna of eurypterids in a bad state of preservation, but associated

with fossils of marine origin, in no wise indicates that the merostomes were marine. The Siluric fauna of Bohemia is one of the best illustrations of this class, and I shall consider it in detail.

Barrande's work on the faunas of the Palæozoic rocks of Bohemia has conclusively shown that the trilobites and other crustacea, as well as the eurypterids reached their acme in numbers in the Siluric, constituting the third fauna E. The upper part of this showed a far more prolific development of life than did the lower, as is readily brought out by the following figures. In the Lower Siluric (E e_1) Barrande records sixteen species of trilobites and ten species of other arthropods among which he includes phyllopods, ostracods, eurypterids and cirripedes; for the Upper Siluric (E e_2) the corresponding figures are 82 and 24, making a total of crustacea (and eurypterids) for the Lower Siluric of 26, for the Upper 106. Furthermore, the crustacea, though represented by so many species were not the dominant forms of life, for the Siluric, especially the upper part, marked the period of greatest development of the cephalopods which were represented by 665 species. As I stated in an earlier part of the paper, Barrande does not give horizons of smaller taxonomic value than his "bands" which correspond to the first subdivision of the periods, and it is therefore impossible even to approach the niceties of correlation which can be attained in America; one cannot determine the precise level even within several hundred feet for any particular occurrence. However, there is no reason to doubt that all of the Siluric of Bohemia was marine. Considering the nature of the fauna of that period and the number of species which Barrande was able to describe even so early as 1852, his explanation for the fragmentary character of the eurypterids, as due to their having been the food of the cephalopods, seems inadequate. If the trilobites were able to live in the same sea with cephalopods and escape unscathed, so that their remains were preserved in wonderful perfection, why should the eurypterids have been so voraciously attacked? It is doubtful if the eurypterids were of so different an internal nature from the trilobites that they should have been more palatable, nor were their exoskeletons more fragile. In the Siluric sea 814 species of cephalopods are known to have existed, as compared to 97 species of trilobites. Thus there were eight or nine species of Cephalopods to each species of trilobite, while the number of the individuals of the former vastly exceeded that of the latter. Surely in the great struggle for existence which was taking place, the cephalopods, if they fed upon crustaceous animals at all, would scarcely have used such nice selection so that the eurypterids alone were consumed, while the trilobites continued to flourish.

Of a certainty, some more rational explanation must be sought. This occurrence in Bohemia is one of the rare ones in the Siluric in which the eurypterids are found associated with an abundant and unquestionable marine fauna. Yet the facts, that no complete individual has been found, that even the fragments are of so uncertain a character that some which at first were supposed to belong to separate species have with more study been found to belong to the same species, and finally that the eurypterids, of all the myriad organisms which lived in that sea, should have been broken to fragments of which only a few are found—these facts will not admit of explanation on the ground that the eurypterids lived in the sea. They must have lived in some other aqueous realm besides the sea, and one is again led to the conclusion that they must have lived in the rivers. The facts of migration and the relations of the Bohemian forms to those in other parts of the world strongly support this conclusion. (See below chapter V).

CHAPTER V

THE GEOLOGICAL AND GEOGRAPHICAL DISTRIBUTION OF THE EURYPTERIDS AND THE CONDITIONS OF MIGRATION

SUMMARY OF FACTS OBSERVED REGARDING THE DISTRIBUTION OF THE EURYPTERIDS

The anomalies in the geographic distribution of the eurypterids constitute one of the most difficult phases of the problem of the habitat. The facts which have been summarized in the tables on pages 37-49, and which have been discussed in various parts of the paper up to this point, clearly lead to the following generalizations: (1) There are many cases in which single individuals are found separated geologically and geographically from other known eurypterids or eurypterid-faunas. (2) The same or closely related species may occur in regions widely separated, although in the same horizon, in intermediate regions, either no eurypterids at all are found or else those which do occur are not related to those in the other localities. (3) Eurypterids are seldom found in the same chronofauna throughout the world, but appear suddenly, now in one place, now in another at different horizons, and continuous widespread faunas are entirely wanting.

(1) As illustrations of the scattered occurrence of single specimens of eurypterids may be mentioned: *Strabops thacheri* in the Upper Cambric, *Echinognathus clevelandi* from the Utica, *Eurypterus prominens* from the Clinton, *Eurypterus boylei* from the Guelph, *Eurypterus microphthalmus* from the Manlius, and *Eurypterus douvillei* from the Rothliegende.

(2) As an instance of the same species occurring in places many miles apart, *Eurypterus remipes* may be cited. This species has been found in Waterville, Oneida County, N. Y. in great numbers; at Jerusalem or Wheelock's Hill, Herkimer County; to the northeast (near Cedarville) and west (Paris Hill) of Jerusalem Hill, near Oriskany; at Cayuga Junction, Cayuga County; and possibly at Buffalo. In all of these localities it has been found in the uppermost part of the Bertie, but at Seneca Falls, Seneca County, specimens have been found in the Rondout Waterlime (which may be possibly of the same age as the Bertie). There are several cases of closely related species occurring in localities separated often by great distances. One example that may be cited is that of *Eurypterus lacustris*, *E. remipes* and *E. fischeri*. For a long time the Baltic form (*E. fischeri*) was identified with *E. remipes* and it was not until Eichwald pointed out the differences in surface sculpturing and certain other characteristics, that the species was made distinct. Clarke and Ruedemann conclude their discussion of the comparion of these two species by saying that, "Altogether, the differences are so small that Schmidt's suggestion that they are but geographical varieties is fully supported" (39, 172). They add, further, that *E. remipes* and *E. lacustris* "are more closely related to each other than either of them to *E. fischeri*, indicating that they had but lately separated. Their differences rest mainly in the shape of the carapace and they are duplicated by those between *E. fischeri* and *E. laticeps*, two forms associated in the same [Baltic] rocks" (39, 172). *Eurypterus fischeri* has been found in Oesel and in Podolia.

(3) The data on the distribution have brought out clearly the fact that at no geological horizon is there a widespread or continuous eurypterid fauna indicating passageways of migration. Even in the Upper Siluric, which marks the acme in all respects for the eurypterids, the fauna does not show that universality which would be expected of denizens of the sea or of organisms whose immediate

ancestors were marine. The Bertie fauna of North America covers an area of not over 1000 square miles. The corresponding European chronofauna is found in the Baltic Isles and Russian Provinces in sediments similar in lithologic character to those in North America, but the areal extent is small and circumscribed. In the Upper Siluric of Bohemia and of Scotland the eurypterids occur within a very limited area. But in the adjoining undoubted marine formations which lie in the path of migration by marine waters, the eurypterids are wanting. The graptolite fauna of the Ordovicic is known throughout the world, but the eurypterids are found only in the small area around Catskill, New York. Similarly, eurypterids are found in the Wenlock shales and limestones of Scotland, but not to the south in England, nor in other Niagaran formations at the same horizon throughout the world.

The tremendous importance of the geological and geographical distribution of the eurypterids has heretofore been overlooked except by Professor Grabau, who has dwelt upon it in the discussion of the most important occurrences, especially in North America. When the factors of distribution are considered throughout the Palaeozoic and on every continent, it will be seen that they constitute the gravest objection of all to any marine, lagoon, or estuarine theory of habitat that has been advanced. Again we must turn to a contemplation of the present, for we must believe that the laws which control the universe have always been undeviatingly constant and will always remain so. Our great difficulty in reading Earth history correctly lies in our failure to learn the laws; so much of the past appears to our view not in the form of causes but of results. In the study of the phenomena of the present, we are usually privileged to see both the causes and the effects, and thus the opportunity is offered to ascertain the laws, although in many cases our lack of knowledge or our unreadiness, prevents us from taking advantage of this opportunity. Thus we fail to learn and to formulate the laws which are operative in every physical fact and phenomenon, visible or invisible. That man we call a master who has discerned the laws; he alone can interpret with truth the marvels of this world and of other worlds; he alone can prophecy, with a reasonable degree of certainty, the things which are to come; and he alone, if he be a geologist, can reconstruct along the lines of truth the former history of our earth. Therefore, it behooves us to become acquainted with the laws which may be studied today, before we attempt to formulate theories about the conditions which obtained in the past. If there were oceans during Palaeozoic time in which large accumulations of clastic material were forming, we are drawn to the reasonable conclusion that there were land masses from which this clastic material was derived. We must also conclude, if we view the matter rationally, that there must have been rivers on those ancient continents and that then, as now, they constituted the principal agents of transportation of material into the sea. And finally, we must believe that if there was any life in those rivers, it must have been subject to the same laws of dispersal as is the life in the rivers today. My statement does not say that because we have life in the rivers now there must have been life in the Palaeozoic rivers; that is obviously untrue. But if there *was* life in those rivers, then it was subject to the same laws which are operative now. It is advisable, therefore, to consider these laws and to formulate them that we may have certain definite principles for future reference.

MIGRATION AND DISPERSAL OF RECENT FLUVIATILE ORGANISMS

Of existing taxonomic groups, the fish have received more study than any other group of fluviatile organisms, and interesting as well as exceedingly pertinent data are at hand in regard to migration and dispersal of this group. Günther in his *Study of Fishes*, makes the general statement that: "The Freshwater fishes . . . . have been spread in *circumpolar* zones, and in but a limited degree from north to south. No family, much less a genus, ranges from the north to the south, whilst a number of families and genera make the entire circuit round the globe within the zone to which they belong. Not even the Cyprinoids and Siluroids, which are most characteristic of the freshwater fauna of our period, are an exception to this. Temperature and climate, indeed, are the principal factors by which the character of the freshwater fauna is determined; they form the barriers which interfere with the unlimited dispersal of the ichthyic type, much more than mountain ranges, deserts, or oceans" (**97**, 215).

A few illustrations of this widespread dispersal of fishes in circumpolar zones will show that the above statement is not merely theoretical. These illustrations are selected, but taken verbatim from Günther's work (**97**, 209–211).

A. SPECIES IDENTICAL IN DISTANT CONTINENTS. 1. A number of species inhabiting Europe and the temperate parts of eastern North America, as *Perca fluviatilis*, *Gastrosteus pungitius*, *Lota vulgaris*, *Salmo salar*, *Esox lucius*, *Acipenser sturio*, *A. maculosus*, and several Petromyzonts.

2. *Lates calcifer* is common in India as well as in Queensland.

3. *Galaxias attenuatus* inhabits Tasmania, New Zealand, the Falkland Islands, and the South American continent.

B. GENERA IDENTICAL IN DISTANT CONTINENTS. 1. The genus *Umbra*, so peculiar a form as to be the type of a distinct family, comprises two most closely allied species only, one of which is found in the Atlantic States of North America, the other in the river system of the Danube.

2. A very distinct genus of Sturgeons, *Scaphirhynchus*, consisting of two species only; one of these inhabits the fresh waters of Central Asia, the other the system of the Mississippi.

3. A second most peculiar genus of Sturgeons, *Polyodon*, consists likewise of two species only, one inhabiting the Mississippi, the other the Yang-tse-Kiang.

4. *Amiurus*, A siluroid, and *Catastomus*, a Cyprinoid genus, both well represented in North America, have a single species each, in temperate China.

5. *Lepidosiren* is represented by one species in tropical America, and by the second in tropical Africa (Protopterus).

6. *Galaxias* is equally represented in South Australia, New Zealand and the southern parts of South America.

C. FAMILIES IDENTICAL IN DISTANT CONTINENTS. 1. The *Labyrinthici*, represented in Africa by 5, and in India by 25 species.

2. The *Chromides*, represented in Africa by 25, in South America by 80 species.

3. The *Characinidae*, represented in Africa by 35, and in South America by 226 species.

4. The *Haplochitonidae*, represented in southern Australia by 1, in New Zealand by 1, and in Patagonia by a third species.

The facts regarding the distribution of freshwater fish show that it is not uncommon for identical families, genera and even species to be found living in rivers on opposite sides of the world without any known relatives in the intervening rivers. There seems to be no limit to the distance which freshwater fish may migrate in the same circumpolar zone; while even mountains, deserts, or oceans, do not offer absolute barriers. It is thus easy to see that migrations which would be impossible for marine forms offer no difficulties to freshwater organisms, and localized occurrences which would be inexplicable for the former are easily understood for the latter. I do not mean to imply that migration of river forms all around the world can take place always in a single geological period. It is well known that certain related or identical species of fish which today are found in rivers thousands of miles apart have such a distribution because their ancestors in a former geological epoch when relations between land and sea were different had an opportunity to accomplish the migrations, all evidences of which have since been destroyed. In distributions observed today we see the result of migrations which may have taken place ten thousand or ten million years ago. Thus Günther observes that the present occurrence of the *Dipnoi* on the continents of Africa, South America and Australia is consequential upon their wide range in the Palæozoic and Mesozoic, while that of the Siluroids, which have an even greater range, is the result of their distribution during the Cenozoic. It may be well to refer here to the theory of the independent origin of specific characters, in widely dispersed organisms, which are, nevertheless, placed under similar or identical physical conditions. This theory has been especially applied to the fishes of South America by Hasemann (**110**), who has shown how further complications arise through the production of apparently identical though actually unrelated species in response to similar environmental complexes.

SUMMARY. Observations upon freshwater fishes have brought out the following facts as to dispersal and migration:

1. Dispersal and migration take place in circumpolar zones the range of migration depending upon: (a) temperature, (b) climate, (c) euryhalinity or stenohalinity of species, genera, etc., (d) vitality of given individuals to withstand sudden changes in temperature, in salinity, or in the amount of available water and food supply.

2. The interlacing of the headwaters of mighty river systems oftentimes accounts for the occurrence in the lower reaches of rivers hundreds of miles apart of identical or closely similar genera and species. The case of the trout on the North American continent is a familiar illustration. In the interlacing headwaters of both the Columbia and Missouri rivers occurs the cut-throat trout, *Salmo clarki*. Various species are gradually differentiated away from the headwater region. Thus the nearest relatives of *S. clarki* are *S. virginalis* in the basin of Utah, and *S. sternias* of the Platte River. "Next to the latter is *Salmo spilurus* of the Rio Grande and then *Salmo pleuriticus* of the Colorado. The latter in turn may be the parent of the Twin

Lakes trout, *Salmo macdonaldi*. Always the form next away from the parent stock is onward in space across the barrier" (Jordan, **134**, 547). Migration from the headwaters of one system to those of another only a few miles distant is accomplished: (a) as a result of river capture, (b) by the accidental transportation of the eggs of fishes, by birds, from one stream to another, (c) by the temporary formation of connecting streams or lakes between two river systems in a period of torrential rains, (d) by the temporary or permanent shifting of the watershed between two systems by a slight geological change, (e) by actual migration of fishes over areas where there are not continuous waterways. "Some fishes, provided with gill-openings so narrow that the water moistening the gills cannot readily evaporate; and endowed, besides, with an extraordinary degree of vitality, like many Siluroids (*Clarias*, *Callichthys*), eels, etc., are enabled to wander for some distance over land, and may thus reach a watercourse leading them thousands of miles from their original home" (Günther, **97**, 212).

3. A shallow body of salt water between two continents may, by a very slight negative eustatic movement, be drawn off and a dry land connection will be afforded which will enable easy migration for freshwater fishes from one continent to the other. A subsequent positive eustatic movement would conceal the route of migration and one would have to deal with some apparently inexplicable occurrences of identical species.

4. "From the great number of freshwater forms which we see at this present day acclimatised in, gradually acclimatising themselves in, or periodically or sporadically migrating into, the sea, we must conclude that, under certain circumstances, salt water may cease to be an impassable barrier at some period of the existence of freshwater species, and that many of them have passed from one river through salt water into another" (Günther, **97**, 211).

These facts which have been found out in connection with the distribution of freshwater fish of the present are essentially true for those inhabiting the rivers of all earlier continents. They may, furthermore, be considered as equally true for the eurypterids who were highly organized gill-breathers and many of whom were powerful swimmers. While they lacked one of the modes of transportation from the headwaters of one river system to those of another in not having the possibility of accidental portage by birds they had, on the other hand, a far more important means, for they had walking legs, and it is possible that they might have been able to withstand exposure to the air for several hours. In passing from one stream to another their locomotion would be fairly rapid and their migration in this manner might not have been infrequent.

APPLICATION OF PRINCIPLES DEDUCED FROM MODERN FAUNAL DISTRIBUTION[1]

By the discriminating use of the laws which have been observed to be potent in directing the migration of fishes and other organisms living in the rivers at present, and without making any unwarranted assumptions, it seems safe to postulate the following expectabilities in regard to the geological and geographical distribution which we should be able to find among the eurypterids, providing they lived in the rivers.

1. Unless, as some have supposed, but which is very improbable, there were no climatic zones in the Palaeozoic, and conditions of temperature were equable over the whole globe, related or identical species of eurypterids should be found in deposits geographically situated in a circumpolar zone, not necessarily the same as the climatic zones of the present.

2. Eurypterid remains should be expected to occur in deposits of limited areal extent marking lake sediments, flood plain deposits, or littoral deposits in the sea at or near the mouths of rivers.

3. Eurypterids which inhabited the streams of one river system would be more closely related than those living in the tributaries of different and entirely distinct systems, and in general this would mean that forms which lived in the rivers of one continent in any period, would constitute a group of related genera and species, while those living in the rivers of another continent would constitute a distinct group, the individuals of which would be related; and if the different continents should remain unconnected for a long time, geologically, distribution and evolution would continue on each land mass, but we would not expect any of the individuals from one continent to migrate to another, so that succeeding faunas should not show intercontinental affinities, though phylogenetic relations should be discernable on each continent. It must be remembered, however, that remains of faunas from both continents might be carried into basins which received the simultaneous drainage of rivers from each.

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[1] The importance of distinguishing between *dispersal*, the passive and *migration*, the active distribution of organisms has been insisted upon by Grabau (*Principles*, p. 1041).

4. In deposits which, from the study of their lithogenesis can be shown to have come from the same Palaeozoic continents, should be found remains of eurypterids in circumscribed areas as stated in "2" above, and the genera and species, while not necessarily having any near relatives in adjoining deposits, may be identical with forms whose remains are found in a formation perhaps two or three thousand miles distant, but *on the same ancient continent.* Such relationships are to be accounted for by migration from a common source where the headwaters of two or more river systems interlace (see p. 205 above).

5. The distribution of eurypterids would not have had any necessary connection with those organisms living in marine chronofaunas, and consequently, except when eurypterid-bearing deposits merge into thalassigenous ones, or when fragments or stray eurypterids have been washed out to sea, when intercalation between marine deposits would give the age, eurypterids would not serve as good index fossils.

6. Eurypterids would not suffer rapid changes in evolution, since it is a well known fact, that fluviatile types are often persistent for a long period of time. Thus the cray-fish *Cambarus primaevus* Packard of the Green River beds (Eocenic) of Wyoming, is a near relative of the modern *C. affinis* of the same region, a similarity due no doubt to the persistence of the type in essentially the same river basin during the interval.

Zoölogists and palaeontologists who have made detailed studies of the distribution of modern freshwater faunas are thoroughly agreed that accurate results are not to be obtained merely from observations on present distribution. It is an absolute necessity to study the fossil faunas and especially the palæogeography. The reason for this will be evident after a very little thought. If in the Lower Cretacic when there existed the Nearctic continent, comprising most of North America, and continuing across the North Atlantic through Greenland and western Europe, and including the Scandinavian mass, a family of some fluviatile organisms had arisen in the central Canadian area, quickly spreading from one river system to another and finally reaching Europe, we would find in the rocks of that period, that many of the genera on the two modern continents were the same, and that there would be quite a goodly number of identical species. The descendants of these Lower Cretacic organisms would develop on the two continents, (i.e., the two sides of this old nearctic land mass), and the species in the lower reaches of the rivers would diverge in their characters more and more from the parent stock. Those forms which came under the same environmental conditions might, and experience shows that they would develop along parallel lines, appearing in later geological times as similar or even what might be called identical species. In the course of centuries emigrants from an earlier home centre of distribution would pass from the headwaters of one stream to those of another, and soon these forms which had been passing through their individual modifications under one set of environmental factors would migrate down the rivers and mingle with those forms which had in an earlier period sought the lower reaches of the rivers where a different complex of environmental factors obtained, and there the old immigrants and the new, would come to live in the same waters. A single family, in this way, would give rise to a certain number of primitive genera, some of which would migrate far from the original centre of distribution. The descendants of these early immigrants might, after a long time and after having suffered profound morphological changes, return to mingle with the descendants of the provincial forms which had never left the ancestral region. Now let us think of such inter-changes going on across the Nearctic continent all through the Tertiary until at the close Europe was separated from North America by an advance of the sea. At once we have two separate continents and two river faunas. Were one to try to account for the distribution of the fluviatile forms now living in the rivers by a study of the present geography, one would be in despair to account for the similarity or seeming identity of many species on opposite sides of the dividing waters. Evidently the only mode of attack is by the study of successively earlier and earlier fossil faunas and by the slow reconstruction of the palaeogeography for each of those periods. One need not search far to find the application of these hypothetical statements to the eurypterids. If they were river-living organisms then it is clearly impossible to explain their distribution in any particular period without considering their distribution in each immediately preceding period. No one has ever done this because each writer tried to account for eurypterid occurrences on a hypothesis of marine distribution.

The results of migration are very different for marine organisms, because of the fundamental difference between the continuity of the seas and the discontinuity of the lands. Marine faunas, especially the vagrant benthos of the littoral zone and the pelagic ones, tend to be widespread, for they have greater freedom in the size of life districts available, and in the lesser competition, as compared with the lineal extent of rivers and the great struggle for existence, particularly between crustaceous animals. For instance, Ortmann has pointed out that freshwater crayfishes existed in Southeastern Asia, the Malaysian Islands, India, and Madagascar in the Middle Cretacic. In the Upper Cretacic the freshwater crabs (which are geologically younger than the crayfishes) arrived (or originated) in *Lemuria* and "extended into Southern Asia and the Malaysian Archipelago, everywhere exterminating the crayfishes, namely, in India, Southeastern Asia (Farther India and China) and on the islands. They not only acted as a check to the distribution of the crayfishes, but directly annihilated them" (Ortmann **201**, 391). As a result, no crayfishes are today found in the rivers of central and south Asia or on the Malaysian Islands.

We have previously seen that in river faunas the number of individuals is large but the number of genera and species is small, while in marine faunas genera, species, and individuals are abundant. The factor, then, of relative numbers of taxonomic groups would favor marine organisms in widespread migrations. Pelagic and vagrant benthonic organisms, living in the sea, have on the whole rather favorable conditions for migration. With river forms the factors of distribution are more accidental and much depends upon the individual. In the region of interlacing headwaters, streams of different systems are temporarily connected at times of flood and perhaps only two or three individuals of a certain species will change from one system to another, and then, when the connection is broken, the distribution of that species depends entirely upon the ability of the individual to contend with all of the new factors in the environment, and it is pure survival of the fittest which brings about the distribution of that species. In the sea, on the other hand, whole groups migrate or are carried by currents, and the chances are good that a large number or at least enough for populating a new region will survive, whatever vicissitudes befall. Thus, to sum up, distribution of river forms over broad areas is more precarious and fortuitious than is the case with marine organisms.

When we apply such considerations to fossil faunas, to a class of organisms wholly extinct, where we have no facts of modern distribution to help us, no facts of present habitat to point past modes of life, we can see that the criteria which we apply to such fossil faunas in the determination of relationships and migrations must be quite different from the ones applied to marine fossil faunas. We can now understand that a fauna may be made up of individuals which show a fairly close relationship with faunas in neighboring areas, but may contain one species which is identical or nearly so with a species in a fauna three thousand miles distant. If these were marine fossils we could not understand such a thing, because marine faunas show whole groups of species in one region related to groups in another, and contemporaneous marine deposits in the path of migration show similar related groups. But the routes of migration for river forms would almost never be shown to us in the rocks, because rivers in their upper and middle portions degrade and would continually be carrying away the traces of their history which would be recorded only in deltas or flood plains. Thus, contemporaneous and related fluviatile faunas would appear geographically at the outer ends of the spokes of a great wheel which has its hub at the centre of dispersal. The remains of synchronous faunas would of necessity appear scattered over the face of the earth, without any apparent connection; a fact which would be inexplicable if the faunas were interpreted as marine. The only way to solve the problem of the distribution of those forms would be through a study of the palæogeography of the period in which they occurred and of all preceding periods in so far as was possible.

When stratigraphers come fully to appreciate the value of continental deposits and faunas, they will have taken a big step toward the unravelling of the palæogeography of our earth. No one would attempt to restore the conditions of land and sea in the Tertiary without making use of the migrations of mammals and other terrestrial organisms, for it is evident that while a study of marine faunas will show the position of the oceans and epicontinental seas in any period, the exact configurations of the continents, the exact location of land barriers and connections can only be determined by the migrations of the animals and plants living on the land or in the rivers. This applies with as great truth to the Palaeozoic as to the Tertiary, and while the aid of plants cannot there be invoked until the end of the period, I hope to show before concluding this paper that the eurypterids will be of vast service in helping to locate Palaeozoic rivers and routes of migration from one continent to another.

MIGRATION AND DISTRIBUTION OF THE EURYPTERIDS

THEORY OF EARLY MARINE HABITAT AND ROUTES OF MIGRATION. As I stated above, the anomalies in the distribution of the eurypterids have not usually been given much consideration, though they are of the utmost importance. There is a current opinion that has somehow been formed about the bionomy of the eurypterid faunas and no one thinks of challenging it. When a eurypterid fauna has been found in a place where a marine fauna was not expected, it has had to be made to fit in with the preconceived opinion about the bionomic facies in which eurypterids are supposed to occur. It has been spoken of as a "most unusual occurrence;" "one which is most interesting because found in beds formerly supposed to be devoid of marine fossils," and so on. Again we read of the clear evidence of a marine passage between the Buffalo region and the Baltic area, because two almost identical species of eurypterids are found in these localities. Formations are declared to be marine because they contain eurypterids, and eurypterids are held to be marine, because they occur in formations considered on *a priori* grounds to be marine. Every writer seems to feel it necessary to fit the eurypterids into a marine or estuarine habitat; where the facts refuse to fall into line, they are cited as ineresting because they fail to, or else they are consciously suppressed or carelessly overlooked. The prevailing opinion as to the bionomy of the successive eurypterid faunas is as follows: Until well on in the Siluric the eurypterids were purely marine forms living in the seas and, inferentially, associated with the marine organisms therein. Toward the middle of the Siluric, the eurypterids all over the world left the seas and migrated into the various brackish water bodies then existing, seeking the mouths of rivers, the bays, lagoons and interior cut-off arms of the sea. From that time until the end of the Palaeozoic, they are supposed to have sought water of ever-decreasing salinity until they became entirely freshwater denizens. Their geographical distribution is accounted for by an assumed migration from one estuary or lagoon to another along the shores of various Palaeozoic continents.

OBJECTIONS TO MARINE HABITAT THEORY. If this succession of events is the correct one, then the following question arises in connection with the distribution: If the eurypterids lived in pools or in marginal lagoons on the seashore, in estuaries, bays or cut-offs how did they get there to begin with?

The question is generally answered by the statement that the eurypterids originally lived in the sea and then migrated to the various marginal water bodies and estuaries where they and a few peculiar crustaceans constituted a brackish water fauna. I have already shown (p. 70) that a "brackish water" fauna consists of modified marine and freshwater euryhaline organisms with a preponderance of marine types, and that the latter show particular characteristics such as dwarfing and thinning of the shell, but that such a fauna has representatives of nearly all invertebrate phyla and is not made up of a single class of organisms. But let us assume for the sake of argument that the eurypterids and a few other arthropods did form a brackish water fauna; then another assumption is necessary, for, if a class of organisms as a whole, such as the eurypterids, should in any given geological period migrate from the sea to estuaries or other brackish water bodies and at the same time should no longer be able to live in the sea, and should not, on the other hand, become adapted to river water, then the remains of such a class of organisms should be restricted to the geological period in which the migration took place, for the class could not persist unless the estuaries persisted from period to period in the same locality (see objection to this on p. 215 below).

But since the class is known to have persisted from period to period, as indicated by the occurrences of their remains in the rocks, we are forced to conclude, on the assumption that the organisms migrated from the sea to the estuaries, that there was a persistent marine stock to repeople each successive estuary. But, if that were true, then eurypterid remains of the same or allied species should be found entombed with the marine organisms of the period in the marine equivalents of the estuarine or other brackish water deposits, and the eurypterids should have constituted a part of the typical marine fauna. But it has been shown again and again that in the contemporaneous marine deposits with typical and undoubted marine faunas, no eurypterids are found, as, for instance, in the marine Wenlock of England, or the marine limestones of the Famennian of Germany. If there is no indication of such a persistent marine stock, then there must have been a persistent stock in the rivers to repeople the estuaries in the successive geologic periods. These arguments may be applied specifically to the Siluric and Devonic of North America. During the Lower Siluric (Niagaran), the eurypterids are supposed to have lived in the sea. During the remainder of the Siluric they are assumed to have lived in or along the shore of a shallow, epicontinental sea having a connection with the Atlantic or other waters to the east. In this restricted sea terrigenous deposits were formed, well represented by the Shawangunk delta. In the pools along shore, where, on account of the more sheltered conditions, only muds were accumulating, the young eurypterids lived. The larvæ were hatched in these pools and the early stages in the ontogeny were passed through, then the mature individuals sought the deeper littoral waters. Thus do Clarke and Ruedemann explain the presence of the abundant fauna composed almost entirely of young individuals in the Shawangunk shales at Otisville, New York, and, during the same period, the closely related but mature individuals in the Pittsford shales at Pittsford, New York.

A comparison, species by species of the forms from the Pittsford and Shawangunk will be given below (p. 225), and it will be seen to show that the two faunas are very closely related, indeed, almost identical except in the size of their individuals, and in the presence, in the Pittsford, of a species of Eurypterus related to a Bertie form to be considered presently. Such similarity might, if taken alone, seem to substantiate the "lagoon" theory. But it is usually impossible to draw very accurate or very far-reaching conclusions from the consideration of faunas or of deposits in a single circumscribed area or at a single horizon; one must take into account the palæogeographic conditions in neighboring regions and finally throughout the whole continent if not, indeed, the whole world, and one must consider the source of supply of sediments, the possibilities of migrations of faunas and the absolute necessity of a fauna to have a medium in which it can live from one period to another, unless we wish to revert to the belief in special creations. Thus, bearing these things in mind, we must account for the origin of the sediments of the Pittsford and Shawangunk and of the succeeding formations, the various waterlimes, which contain eurypterids. It has been demonstrated on pp. 10c–6. that the conglomerates and shales of the Shawangunk and the shales of the Pittsford must have come from Appalachia, carried northwards by various rivers.

Now, assuming for the sake of argument that the succession of events during Salina time was that outlined above (p. 212) then the following conditions are implied: (1) The Pittsford and Shawangunk faunas must have constituted the ancestral stock for the Bertie fauna of Erie and Herkimer counties. (2) Throughout the long period from

Pittsford to Bertie time, one or several rivers must have occupied approximately the same position, so that the Pittsford and Shawangunk faunas could escape into the estuaries when the Salina sea became too salt, and could remain there in the brackish water part of the estuary until Bertie time, when they appeared in two localities, at Buffalo, 75 miles west of Pittsford, and around Herkimer, 130 miles east of Pittsford. Taking up the first condition, we are confronted with a grave difficulty if we try to think of the Pittsford and Shawangunk fauna remaining in the Salina "lagoon" or at the mouths of estuaries flowing into that inland body of water during Vernon, Syracuse, and Camillus time, for it is evident that we must consider the Pittsford-Shawangunk eurypterids as the ancestors of those found in the Bertie, if we believe in this estuarine theory. In the succeeding pages, where I shall consider every species of eurypterid as an entity and as a member of a faunule, unless it be an isolated form, and where I shall take up the possible modes and routes of migration of species and of faunas, I shall show that the Pittsford-Shawangunk eurypterids were not the ancestors of the Bertie forms, and therefore the first condition which I mentioned at the beginning of this paragraph as a logical deduction from the "lagoon-estuary" theory is impossible, in which case it would appear that the Bertie eurypterids had no ancestors. Let us suppose, however, for the sake of argument, that the Pittsford-Shawangunk fauna did constitute the ancestral stock for the Bertie fauna and that in the dry and at times uncomfortably saline conditions of Salina time the eurypterids left their lagoon and went into the estuaries and even part way up the rivers, seeking proper salinity of water; then we should look for estuarine deposits of mud or perhaps coarser clastics in the Salina of central and western New York, and for the remains of marine organisms which are characteristic of such deposits. (For criteria of estuarine deposits see p. 77 above.) But we search in vain for estuarine, or delta, or flood-plain deposits in that region. Following upon the Pittsford are the Vernon barren red shales with their evidences of subaërial deposition with thorough oxidation (Grabau, **84, 86a, 87**), and then the Syracuse salt deposits. All of this has been discussed before, and the evidence is clear that there existed no estuaries in the area under question in which the early Siluric eurypterids might have sought refuge. Thus, descendants of early Salina "lagoon" species had no place of retreat during later Salina time, and must have perished of drought, and we see that the Bertie eurypterids were doubly deprived of ancestors if they had to depend upon the Pittsford-Shawangunk fauna.

THEORY OF RIVER HABITAT. To pursue this marine-lagoon theory to its logical conclusions in every case would use up many pages of print and would always lead to absurdities, impossibilities or contradictions. Therefore, without dwelling longer on the perplexities and inconsistencies attendant upon this theory, I shall pass at once to the development and exposition of the theory of river habitat. Throughout the Palæozoic there were in existence in the northern part of the western hemisphere three continents which, though varying much in size from period to period, often becoming confluent and at times even being largely covered by the epicontinental sea, nevertheless preserved a marked degree of integrity. These three continents were (1) *Appalachia*, which occupied what is now the eastern border of North America, and constituted the northward projection of the land mass now known as South America, and which supplied the greater part of the clastic materials deposited in eastern North America throughout the Palæozoic; (2) *Rockymontana*, which lay for the greater part of its length on the present continental mass extending from Mexico to Alaska, a palæocordilleran chain, from which clastic sediments were derived which were deposited on the western border of North America and along the continental shelf; (3) *Atlantica*, the great northern North American and northwestern European continent one portion of which, the Canadian shield, was formerly supposed to have been the source of nearly all of the Palæozoic clastic deposits over what is now the United States. Throughout the Palæozoic this Canadian area was usually connected with the Scottish and Scandinavian masses by a broad strip of land extending across the North Atlantic (see map, fig. 8). There was a fourth and smaller continent, *Mississippia*, occupying the area of the Mississippi valley, which at times was entirely covered by the sea, and again formed a part of Rockymontana. Each of these continents had its own river systems, the organisms living therein being subject to the laws of migration and dispersal which are seen to be operative now. Furthermore, the fluviatile fauna of each continent would be distinct as a rule. If, however, migration in circumpolar belts occurred and fluviatile organisms from one continent passed to another, these migrant forms would yet show their closest affinity not to species living in the rivers of the continent to which they were immigrant, but to those in the rivers of the continent from which they emigrated. In any given period faunas which can be shown to have come from rivers on the same continent should be more closely related than faunas coming from rivers of different continents, but there may be single cases of a family, a genus, or even a species which occurs in sediments from one land mass, which is nearly related to or identical with one in sediments coming from another land mass. In such a case, to determine true relationships one must compare the whole of each fauna, species by species, and must in addition study the ancestors of each fauna and of each species in the preceding periods wherever possible.

THE EURYPTERID FAUNAS CONSIDERED BY CONTINENTS

The Eurypterid Faunas of Appalachia. Let us turn now to the placing of the various pre-Siluric eurypterids. *Strabops thacheri* from the Cambric is too primitive and morphologically undifferentiated to be looked upon as more than an ancestral form approaching the prototype and from which several branches of the eurypterid tree diverged. The first prolific eurypterid fauna in North America, the first to offer sufficient material and a large enough representation in genera and species to make it possible to state what are the general affinities of the fauna as a whole, is the newly discovered one in the Normanskill shales at Catskill, New York, which has so far been found to contain six species, included in five genera, but undoubtedly many more will be discovered as the material is worked over. On account of the fragmentary nature of the abdomina found, and because the carapaces are usually dissociated from the rest of the body, generic determinations have been provisional and comparisons with related species difficult. Yet the fauna shows a pronounced and altogether surprising similarity to that of the Schenectady beds (Trenton) despite the difference in age. In the case of *Pterygotus*? (*Eusarcus*) *nasutus*, Clarke and Ruedemann "have been unable to distinguish the Schenectady and Normanskill types," (39, 412); and have referred a number of carapaces from the Normanskill beds to *P. nasutus*, a species described originally from material from the Schenectady shales. *Eusarcus linguatus* from the Normanskill is very similar to *Pterygotus*? (*Eusarcus*) *nasutus*.[2] *Eurypterus chadwicki*, *Dolichopterus breviceps*, and *Stylonurus modestus* are not well enough represented for relational comparisons to be made, so far as species are concerned. The finding of several Stylonurus carapaces, attached ab-

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[2] Clarke and Ruedemann point out this similarity, but claim also that *E. linguatus* "strongly suggests the *Eusarcus vaningeni*" from the Salina, in position of eyes and shape of carapace (39, 414). A close examination of their descriptions and of all the figures they give does not reveal any marked similarity.

domina, and one with a portion of a leg, so early in the Ordovicic in muds derived from Appalachia is most suggestive. In the succeeding Schenectady beds in the same general region, in muds also washed down from Appalachia, occur a number of specimens which, in the shape of the carapace, position of the eyes, etc., suggest their generic reference to Stylonurus and have been described by Clarke and Ruedemann as *S.? limbatus*. They have furthermore found a number of body segments "which have the form and ornamentation of the Otisville species *Stylonurus myops*" (**39**, 296). Although it is a little out of chronological order to bring in the Utica species before taking up the Schenectady fauna, this, nevertheless, is the logical place for its discussion. *Echinognathus clevelandi* was described from a single endognathite which has shown two diagnostic characteristics, namely. an extreme spinosity, and a peculiar and distinctive type of surface sculpture. Clarke and Ruedemann state that this species "was either closely related to Stylonurus or had a convergent development to that genus as far as the two characters mentioned are concerned" (**39**, 322). It may quite properly be asked why it is that if the single endognathite known, shows only two diagnostic characteristics, and these two are recognized as definitive of Stylonurus, the species does not belong to that genus, or at least is it not more than likely, if more specimens are discovered, showing other parts of the body, they will be found to represent Stylonurus? It seems to the author that the geographical and geological position of *E. clevelandi* alone would suggest the greater possibility of the form being a Stylonurus. To be sure, this is somewhat speculative, but it is a suggestion for future work and consideration; it is sufficient that the Utica species is at least closely related to the genus Stylonurus which was found at earlier periods and also in the Siluric and Devonic, always in deposits derived from Appalachia. This statement includes the Utica beds just mentioned, for it is now recognized that, as Professor Grabau first pointed out, the muds were carried down from Appalachia and were merely the eastern near-shore facies which replaced that of the Trenton limestone facies (Grabau, **84**, 231–232). Passing on to the next time in the history of North America when the genus Stylonurus is known to occur, we find *S.* (*Ctenopterus*) *multispinosus* in the Pittsford and two well defined species of this genus, as well as many fragments specifically indescribable though evidently distinct in the Shawangunk, both of which formations have been interpreted on stratigraphic grounds and on a comparison of the two faunas *inter* *se*, but not for any phyletic reasons, as derivatives from Appalachia, the Pittsford constituting the upper part of the Shawangunk (see p. 101 above). The problematic form from the Portage sandstone referred to *S.*? *wrightianus* is too incomplete to be of much value. It probably belongs to Stylonurus; it certainly occurs in an otherwise unfossiliferous deposit which has been interpreted by Grabau as partly of river floodplain and partly of wind-blown perhaps loess-like origin (**87**, 553, 569). Finally, the Upper Devonic yields two species of Stylonurus: one, *S. beecheri* described from a single individual, none too complete, from the Chemung sandstones of Warren, Pennsylvania; the other *S.* (*Ctenopterus*) *excelsior* from two specimens from the Catskill beds of New York and Pennsylvania. This latter species is related in many respects to *S.* (*Ctenopterus*) *cestrotus* from the Shawangunk, both belonging to the same sub-genus. The Catskill is a continental deposit whose material as shown first by Grabau (**86**) and later by Barrell was derived from Appalachia. The specimens of *S. excelsior* were beyond a doubt washed out into the Chemung sea, since all of the species of Stylonurus so far known from North America came from Appalachia, as has just been demonstrated.

Having now followed the history of this one genus from Ordovicic through Devonic time and found that it always lived in the rivers of Appalachia, let us return to the genus Dolichopterus in the Normanskill beds, and trace its subsequent occurrences. As in the case of Stylonurus, the specific relations of the Normanskill form cannot be determined, for only a single small carapace is known, but the point of especial interest is the occurrence thus early of a Dolichopterus. This genus is represented by two species certainly, and one doubtfully, in the succeeding Schenectady beds. Two specimens described under the new species of *D. latifrons* by Clarke and Ruedemann agree "closely with *D. otisius*" from the Shawangunk in the posterior contraction of the carapace (**39**, 270). The carapaces and metastomes of *D. frankfortensis* (Schenectady) do not seem to show close relationship to other species of the genus, though one metastoma "has been found which recalls that of *D. macrochirus*" from the Bertie (**39**, 269). A few fragments having certain Dolichopterus and certain Eurypterus characteristics have been referred to *E.*? (*Dolichopterus*?) *stellatus*, but they are of no value in the present discussion. Thus it is seen that in the meagre, unsatisfactory material from the Normanskill representative of Dolichopterus, one species shows affinities to a Shawangunk form, and one specimen of a second species recalls characteristics of a Bertie species. The evidence is frail, and yet it might seem a little disconcerting to have an individual which came from Appalachia, as we think, showing relationship to one coming from Atlantica, but I shall have a suggestion to make when I come to the Bertie that will do away with even this slight difficulty, which is, after all, entirely negligible, since the only specimen showing relation to a Bertie form is a single metastoma which bears only a suggestion of similarity. Continuing in chronological sequence, the next formation in which a Dolichopterus occurs is the Shawangunk grit where there are two species *D. otisius* with a large representation of carapaces none of which retain more than two body segments, and *D. stylonuroides* of which three carapaces and one more complete individual have been found. The former species has certain characters in common with *D. macrochirus* (Bertie), the young of both being even more alike than the adults. If the two species are phylogenetically related, then the adult *D. macrochirus* has kept the ancestral characteristic of a broad frontal lobe on the carapace, for this is found in the young of both species and retained throughout the ontogeny of the Bertie form, while *D. otisius* in the adult shows a development of this lobe into an angular extension. In this one characteristic, then, *D. macrochirus* would show retardation. The second species in the Shawangunk is rare and shows no close relationship to any known species.

In considering both the Schenectady and Shawangunk faunas, we have seen that there was a species of Dolichopterus in the latter and a single specimen in the former which showed a more or less close relationship to certain species of the same genus in the Bertie. From purely stratigraphic reasoning it is known that specimens of the first two formations were derived from Appalachia, while those of the Bertie came from Atlantica. The question might be raised whether the stratigraphic facts do not conflict with my biological theories, for I have been trying to show that eurypterids found in sediments which were transported by rivers on the same continent should show genetic relationship and should for the most part be distinct from those which lived in rivers on different continents; but the species of Dolichopterus do not seem to conform to this law. In the case of this particular genus with its distribution in time, there would be no apparent physical objection to the accounting for its affinities on the very simple assumption that the Cambric or earlier generic ancestors lived in rivers either on Appalachia or on Atlantica and that during one of the periods when these continents were connected by a strip of land the eurypterids were widely dispersed on both continents; the later consanguinity is thus easily understood. But I think that such an assumption is unnecessary and my reason will be readily apparent when we consider the Bertie species of Dolichopterus, *D. macrochirus*, *D. testudineus* and *D. siluriceps*. The relationship of the first to a species in the Shawangunk has just been discussed. Concerning the second, Clarke and Ruedemann remark: "This species, as represented by the single carapace, is quite similar to *D. otisius*. It differs from the latter mainly by the greater extension of the frontal portion and by the more pronounced posterior contraction of the carapace. The frontal transverse ridge or fold observed in the species is also seen in *D. otisius*" (39, 275). If the two species were genetically related, this more pronounced extension of the frontal portion of the carapace would be predicable in the Bertie species, for according to the laws of recapitulation and tachygenesis a morphological character found in the adult of any species will appear at an earlier and earlier stage in the ontogenetic development of its descendants, and since the apparently orthogenetic tendency in the Shawangunk species *D. otisius* showed a progressive modification from rounded to angular and extended frontal margin, the late Bertie species *D. testudineus* should show a more protruding frontal rim than is found in the adult *D. otisius*. The third Bertie species is *D. siluriceps* of which a single poorly preserved carapace is known, and which cannot be compared to any other species save a small form from the Shawangunk. The genus Dolichopterus is not known from any other country, nor has it been found in beds of later age than the Bertie. Even the three species in the Bertie are so poorly represented that one wonders what happened to the fauna. Of the genotype, *D. macrochirus*, four incomplete though excellently preserved specimens are extant; of each of the other two species there is a single carapace. If these eurypterids lived in the Bertie "pools" of authors, it is inconceivable that not more individuals (or exoskeletons) should have been preserved; if they lived in the rivers coming from Atlantica, this scarcity is accounted for. But the study of the phylogeny of this genus leads me to think that Dolichopterus was confined to the rivers of Appalachia throughout its whole racial history. (Its occurrence in so fragmentary a condition in the Bertie suggests that the few remains were transported from the debouchure of some river of Appalachia and carried into the Bertie muds). There is as yet too little evidence, too many pages in the history are still unread, for a reasonably definite conclusion to be drawn, but I think that such a geographical development and confinement more satisfactorily accounts for the facts which are known than any others. We are not obliged to believe that Dolichopterus always lived in the rivers of Appalachia; the facts of distribution and relationship could be accounted for otherwise; but this belief requires fewer special conditions than the assumption of very early dispersal by rivers on the two continents, while a marine habitat is entirely out of the question. One of the strongest reasons for my conclusion that Dolichopterus was restricted to Appalachia lies in the evidence offered by the origin of the sediments. In the study of any problem if the lithogenesis of the formations concerned points overwhelmingly to one and only one history for those formations, then slight palaeontological incongruities should not be accepted as vitiating the history pointed by the facts of lithogenesis; the apparent incongruities can generally be turned into confirmatory bits of evidence if a broad enough knowledge and a scientifically guided imagination can be brought into play. Thus, when the nature of the outcrops, the lithological characteristics of the rocks, and, most important of all, the consideration of possible sources of supply for material, all point to the continent of Appalachia as the region whence the Normanskill, Schenectady, and Shawangunk deposits must have come, while these same considerations point just as conclusively to Atlantica for the Bertie deposits, then, if a fragment of a eurypterid in the Schenectady shales shows a faint similarity to a form in the Bertie, and if half a dozen specimens in the Bertie waterlime bear a slight or even pronounced resemblance to species in the Shawangunk, we must attempt to visualize the conditions obtaining on the North American continent during the early Palaeozoic and we must seek the most rational explanation, the one most in accord with our knowledge of the laws operating at present, to account for these seeming anomalies. And we should never forget that the geological record has revealed but a few specimens of most species of eurypterids, and that sometimes even a genus is described from a single individual, and that when a writer describes a new species he compares it with the ones already known, drawing analogies where he can; but species which may seem to be very much alike when one has, say, a single member, a carapace, or a claw, of each to compare, might, if a large quantity of perfect material were available, be discovered to be so different that kinship would be found to be entirely lacking where formerly it had been confidently pointed out.

From the great mass of detail which it has been necessary to give, we are at length able to reach two conclusions: (1) Stylonurus from its earliest appearance in the Normanskill beds (Black River or Basal Trenton) to its last appearance in the Chemung was an inhabitant of the rivers of Appalachia; (2) Dolichopterus also first known in the Normanskill, but so far not known from beds later than the Bertie, is most rationally to be considered as restricted in its habitat to the rivers of Appalachia, although the paucity and the condition of the specimens make this conclusion not absolutely certain.

This much being determined, we may consider the remaining faunas which have been found in sediments which from other lines of reasoning are recognized as coming from Appalachia. In the Schenectady shales eleven species are recorded, of which four have already been discussed. Of the remaining seven, *Eurypterus ruedemanni* and *E. pristinus* are represented each by a single carapace neither of which is of use in comparisons, and the same may be said of the doubtfully determined form *Euscarcus* (?) *longiceps* of which a few incomplete carapaces are known. Nine carapaces of *Eusarcus triangulatus* have been found, and these Clarke and Ruedemann state "have in common the broad, short, subtriangular form; and the forward position of the marginal lateral eyes bears a close resemblance to the carapace of *E. scorpionis* from the Bertie waterlime" (**39**, 258). Yet the figures, measurements and descriptions of these two species given by the above mentioned authors do not bear out this "close resemblance." In reference to *E. triangulatus* they say that the carapace is "twice as broad as long (length of type, 20 mm., width 43 mm.)" and of *E. scorpionis* they say that the carapace is about "as broad as long" (p. 234), while in the measurements which they give of this species the length is to the width (in millimeters) as 18: 22, 60: 66, and 56: 59, respectively. For comparison I give outline drawings of the restoration of the carapace of *E. scorpionis* and of the actual carapace of the type of *E. triangulatus* (Figs. 19a and b). One of the commonest species in the Schenectady shales is *Hughmilleria magna*, known from a number of carapaces, some abdomina, and a half complete individual. "This exhibits a form of the preabdomen corresponding to *H. socialis*," but the swimming leg is "relatively longer than that of *H. socialis*" (Pittsford) (**39**, 342). Several detached body rings have been found regarding which Clarke and Ruedemann say: they "exhibit a type of ornamentation, consisting of transverse lines near the anterior margin, known to us only in *H. shawangunk*, the Otisville representative of the genus" (p. 342). Thus the nearest affinities of this Schenectady species are to forms from the Pittsford and Shawangunk, which it has been suggested might themselves be merely growth stages and not "species." Only comparatively young (for the most part nepionic or neanic) individuals are known from the Shawangunk, but it is significant that many of these are almost identical in form of the carapace and the position of the eyes with larger, neanic or ephebic individuals from the Schenectady, indicating relationship by this recapitulation of characteristics in ontogeny (see fig. 20.) The two remaining species of the Schenectady fauna, *Pterygotus* (*Eusarcus*?) *nasutus* and *P. prolificus* are unlike any other species known from this country, so that their comparative value is small. Although the last mentioned species is the most profuse in the Schenectady beds, yet the variability in the shape of the carapaces is so great that one might easily be led astray in drawing conclusions. On the whole, the study of this fauna reveals it to be rather unsatisfactory. For one thing, it is made up for the most part only of carapaces and these are often fragmentary; besides, the forms are so distinctive, possessing such unique and specialized characteristics, that with our present

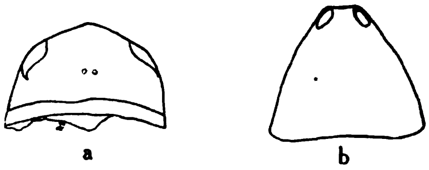

FIG. 19A. *Eusarcus triangulatus*. CLARKE AND RUEDEMANN. × ½.
(After Cl. & R. 1912, pl. LXXXIV, fig. 7)
FIG. 19B. *Eusarcus scorpionis*. GROTE AND PITT. × ½.
(Outline after Cl. & R. 1912, pl. XXVII, fig. 1, restoration)

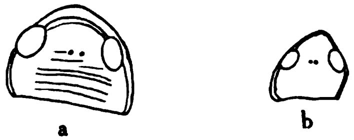

FIG. 20A. *Hughmilleria shawangunk* CLARKE. NEPIONIC INDIVIDUAL. × 8.
(After Cl. & R. 1912, pl. LXIV, fig. 2)
FIG. 20B. *Hughmilleria magna* CLARKE AND RUEDEMANN. × ½.
(After Cl. & R. 1912, pl. LXXXV, fig. 11)

slight knowledge of the various faunas we are unable to perceive relationships which very possibly exist. Two species, however, do show kinship with known forms. *Hughmilleria magna* has characters in common with *H. socialis* and *H. shawangunk* from the Pittsford and Shawangunk, respectively, while *Dolichopterus latifrons* agrees "closely with *D. otisius* from the Shawangunk in the posterior contraction of the carapace." Thus, whatever relationship is indicated between the species of the Schenectady fauna and those of later faunas, is to species in the Pittsford and Shawangunk, all three of which formations have elsewhwere been shown to have had their origin in the sediments from Appalachia. Once again, it appears that rivers coming from the same continent have successive faunas more closely related than those from diverse continents.

Comparison of Pittsford and Shawangunk Faunas. The study of the lithogenesis of these two formations has shown that the Pittsford shale is of the same age as the shales in the upper part of the Shawangunk (p. 101 above), for which reason it is fitting to consider the faunas of the two formations at the same time, especially since the sediments are known to have come from Appalachia in both cases. A comparison of the Pittsford and Shawangunk faunas shows that the two most common species, *Hughmilleria socialis* from the former and *H. shawangunk* from the latter are almost identical. In the shape of the body and form of the head the two species closely resemble each other, while the telsons of the two are identical. As one reads through the description of the Shawangunk form he is struck with the constant similarities in the anatomy between this and the Pittsford species. For instance, Clarke and Ruedemann say in regard to *H. shawangunk:* "The metastoma has not been seen well preserved in position, but we refer several metastomas to this species because they possess on the one hand, the form of that in *H. socialis*, and on the other, exhibit a peculiar, striated ornamentation apparently characteristic of *H. shawangunk*" (39, 345). Again, "The crawling legs appear to have been both short and slender as in *H. socialis*" (39, 344). Because of these similarities, it seems not improbable that *H. socialis* might represent a mature *H. shawangunk*, especially since no specimen longer than 8 cm. is known from the Shawangunk, and no specimen so short as that from the Pittsford, where the individuals are up to 15 cm. in length.

Of the other five species in the Pittsford, *Pterygotus monroensis* is of small importance for it is represented by a single carapace and two fragments. The carapace looks as though it might well belong to a large Hughmilleria; at any rate it has no close affinities to any other species. Similarly, little of correlative value can be deduced from *Stylonurus multispinosus* which is known only from a group of endognathites. In their characteristics they are different from anything in the Bertie (**39**, 297), and are of little relational value.

It will be shown below (p. 232) that *E. pittsfordensis* is closely related to *E. lacustris* in the Bertie, but as will be seen, this is entirely expectable.

In the Shawangunk fauna the most abundant species is *Hughmilleria shawangunk* whose relationship has been discussed under the Pittsford fauna. The very rare forms, *Eusarcus* (?) *cicerops*, *Dolichopterus stylonuroides*, *Stylonurus myops*, and *Pterygotus globiceps*, represented by only a few fragments, show no particular relation to species in any other fauna. Indeed, a comparison of the young of *E. scorpionis* with the young of *E. cicerops* shows that the cephalon was very different in outline and the position of the eyes was not at all similar (Clarke and R., **39**). Similarly, *Stylonurus cestrotus*, found only in a fragmentary condition, "stands apart from all its allies in a number of characters that show it to be an aberrant form" (**39**, 291) *Eurypterus maria*, of which many young and one or two mature individuals have been found, is "greatly different from all its American congeners," (**39**, 190). The relations of *Dolichopterus otisius* have already been pointed out, and it has been shown that while it agrees in certain characteristics with one species, in others it agrees with a different one, so that its affinities cannot be said to be with any particular fauna.

Summarizing the evidence offered in a comparison, species by species, it becomes clear that the dominant, most abundant species in the Pittsford and Shawangunk faunas are alike and that there is only one form in either of these which shows relationship to a Bertie species.

SUMMARY OF FACTS OF DISTRIBUTION ON CONTINENT OF APPALACHIA. The following points may be briefly recapitulated: 1. In the sediments which it has been demonstrated (by myself or others), were with more or less certainty derived from Appalachia, the eurypterids are either unique, showing no relation to known species in North America or other continents, or else they show phyletic relationship *inter se*, the species of later faunas having certain characteristics in common with those of (generally the mature forms of) earlier faunas.

2. Three genera, Stylonurus, Echinognathus, and Hughmilleria were restricted to the rivers of Appalachia.

A far greater interest must attach to the vast northeastern continent of Atlantica which stretched across the north Atlantic and formed a land bridge of vital importance in the migration of the eurypterids. The organisms living in the rivers of this continent were not geographically restricted like those in the rivers of Appalachia, whose remains were washed out occasionally into the surrounding ocean waters, but which were prevented from migration to European fresh waters by the broad expanse of the Palæozoic Atlantic; more fortunate by far were the fluviatile inhabitants of Atlantica, for this continent, we may feel sure, was fairly permanent throughout the Palæozoic, even though the ocean at times encroached over much of the southern part; it was the northern portion that would be vital for the interlocking headwaters of different river systems, and as we shall see there is overwhelmingly convincing evidence pointing to such an intimate relation between the river systems of the periods from the Upper Siluric through the Devonic. Not only were the geographical position and extent of Atlantica more favorable for the widespread dispersion of the eurypterids than were the same physical features of Appalachia, but the sediments derived from the former continent were for the most part of the particular lithological character most favorable to the preservation of organic remains, while those from Appalachia were quite often coarser, being prevailingly sandstones and conglomerates, with only thin beds of intercalated muds. The early differentiation in the character of the clastic deposits from these two continents reflects the still earlier difference which had existed between them in the matter of elevation, for, whereas during Ordovicic and Lower Siluric (Niagaran) time the Canadian area, already peneplaned, had been largely covered by the sea, as indicated by the remnants of Niagaran limestones, and whereas during the same period the Baltic region and that area now forming the southern shore of the Gulf of Finland had likewise been covered by a shallow sea in which coral reefs flourished, the continent of Appalachia on the contrary, had jutted up from the Atlantic with lofty mountain ranges of crystalline rocks. Thus it came about that the rivers in their slow but efficient work of denudation brought into the waters bordering the continent of Atlantica sediments that were calcareous and usually fine-grained (waterlimes) while the rivers of Appalachia carried highly siliceous materials of medium or coarse grain (sandstones and conglomerates) and the winds transported siliceous sands.

THE EURYPTERID FAUNAS OF ATLANTICA. The eurypterid-bearing formations which, mainly on lithological grounds, are thought to have come from Atlantica are (1) Bertie, (2) Rondout, (3) Manlius (4) Siluric waterlimes of Oesel, (5) Waterlimes of Gotland, (6) Wenlock of Scotland, (7) Old Red sandstone. The faunas of these various formations will be taken up in detail with a view to determining the relations between individual species and between the faunas *inter se*.

Of the above mentioned formations and their contained faunas, the first three, which are North American, are quickly disposed of. The Rondout waterlime has thus far yielded but a single species, and this is the same as one from the Bertie, namely, *Eurypterus remipes*. Similarly, only one species is known from the Manlius, a number of specimens, for the most part poorly preserved, having been found in various localities ranging from Albany, Herkimer, Madison and Onondaga counties, New York, to Put-in-Bay, Lake Erie, where it occurs in the stratigraphically older early Monroe beds. Only one specimen has been found in which the abdomen is preserved, the remaining occurrences being only of carapaces, and even these are often poorly preserved. In outline of carapace and lack of ornamentation thereon, this species more closely resembles *E. brewsteri* from the Arbroath paving stones than any form known from North America, though the similarity to *E. lacustris* from the Bertie is not to be overlooked. Thus, the only known eurypterid from the Rondout is the same as a species from the Bertie, and the single species from the Manlius and the lower Monroe shows affinities to one from the Bertie and to one from the Old Red sandstone. With these two so easily dismissed, we may turn to a detailed discussion of the Bertie fauna in which connection it will be necessasy to establish the complete affinities of each species by a detailed morphological and phylogenetic comparison with species in preceding and contemporaneous faunules in America and Europe; the centres of dispersion and the routes of migration must be carefully studied, and the possibilities of fluviatile and marine distribution must be weighed. More deductions can be drawn from the study of the Upper Siluric faunas than from that of any other, because of the abundant data available, the appearance of chronofaunas in widely separated localities and the relative abundance of individuals and species in several of the faunules. Because it is impossible to draw correct deductions regarding the mode of distribution of organisms in any one period from the observation of the distribution visible at that time (see p. 208 above), and since the truth is to be arrived at *only* by the consideration of former land and sea connections or barriers, it is necessary in discussing the Bertie faunule to take into account the palæogeography of preceding periods and the distribution of earlier faunas.

It has seldom been our good fortune to find two succeeding eurypterid faunas in the same locality, so that not many opportunities have been available to trace direct descent; but New York State has been favored in this respect and too much importance can not be attached to the relational values of the Pittsford, Shawangunk, and Bertie faunas.

Comparison of the Pittsford, Shawangunk, and Bertie faunas. As a matter of fact, the Bertie fauna in neither "pool" shows any very marked affinities with the Shawangunk fauna or with the Pittsford, with one exception, already noted, and more fully discussed, below. Of the fourteen species known from the Bertie, there are only four in which even a slight resemblance can be seen to the upper Niagaran forms, and this resemblance in each case (with the one exception noted) is so very small that it cannot be said to constitute a proof of genetic relationship. For instance, *Dolichopterus* (?) *testudineus* from the Herkimer "pool" is represented by a single uncompressed carapace which in outline, general proportions, and the position of the eyes is quite similar to one of the specimens of *D. otisius* in the Shawangunk. But while this general resemblance to one carapace of the Shawangunk form has been pointed out by Clarke and Ruedemann, attention should also be called to the fact that it is very different from one of the best preserved, most typical Shawangunk carapaces of the same species. The sub-elliptical shape of *D. testudineus* is quite distinct from the sub-quadrate one of *D. otisius*, and it does not seem to the author that any genetic relation is indicated between these two forms. To overcome this difficulty of lack of relationship between the Shawangunk and Bertie faunas, it might be argued that the latter was derived from the Pittsford alone. But the only species in the latter which is supposed to have even a semblance of relationship to a Bertie species is *Pterygotus monroensis* which has been compared with *P. cobbi.* The former species was founded on a single carapace, and two other fragments are now known. One of these is the fragment of a free pincer of the chelicera which is thought to belong to *P. monroensis.* This shows one long, rounded tooth at the extremity, then a short tooth, another long tooth but not so long as the first, four short teeth alternating in size, followed by a long tooth, then three shorter ones. The chela of *P. cobbi* from the Bertie shows three long teeth at the end, two short ones, a long one nearly as long as the one at the extremity, then three fairly short ones followed by another long one. The teeth in the chelae in these specimens are similar neither in size nor arrangement, so that no particular relationship is set up between *Pterygotus monroensis* and *P. cobbi* (Fig. 21 a and b).

Not only, then, do the species themselves offer no indication that the Bertie fauna was derived from the Pittsford alone, but, furthermore, it seems impossible to believe that the five Pittsford species included in four genera should give rise to the profuse Bertie fauna of fourteen species included in four genera, two of which are different. The four Pittsford genera are: Eurypterus, Pterygotus, Eusarcus, and Dolichopterus. Clearly, with the exception of *E. pittsfordensis* which will be considered presently, the Pittsford-Shawangunk fauna does not supply the ancestors for the Bertie fauna which is thus left without progenitors on the basis of the "lagoon-estuarine" theory usually advanced. There is also another difficulty. Stylonurus has representatives in North America in the Pittsford and in the Devonic and Carbonic, but none existed in the Bertie waters which should, according to the generally accepted views, have been the one place for the perpetuation of the race of the eurypterids in the late Siluric.

FIG. 21A. *Pterygotus monroensis* SARLE. FRAGMENT OF FREE CHELA. × ½. (After Cl. & R. 1912, pl. LXX, fig. 3)
FIG. 21B. *Pterygotus cobbi* HALL. FREE CHELA OF CHELICERA. × ½. (After Grote & Pitt. 1878, fig. p. 301)

There is yet one other difficulty arising if the Pittsford-Shawangunk fauna was ancestral to the Bertie. How can the many points of similarity between certain Bertie and European species be accounted for? It has already been pointed out that *Eurypterus remipes* from the Herkimer region is so closely related to *E. fischeri* of the

Baltic area that the latter for a long time was identified with the former. Schmidt was the first to suggest that the differences between the two species were only geographical variations arising through migration. With this idea Clarke and Ruedemann have concurred. In fact, they point out in many places the close similarity between the Bertie and Oesel fauna, and especially between the two commonest species in both, *E. remipes* and *E. fischeri*. Now, if the Bertie fauna was an estuarine one, preserved from Pittsford time in various brackish water bodies, when and how did migrations take place to the Baltic sea of the Upper Siluric? The answer will undoubtedly be that the members of the marine stock in the Lower Siluric which were not caught or did not voluntarily seek refuge in the "lagoon" or remnant of Niagaran sea in New York State, migrated along the shore of Atlantica, passing from estuary to estuary until they reached the island of Oesel. This might seem like a very happy solution, if the British Isles did not intervene between America and Oesel, and if they did not have a very clear record to show that no such migration took place. In the discussion of the faunas of the various Palæozoic continents, given below, it will be shown that the Wenlock, Ludlow, and Lanarkian faunas of Great Britain offer no indications of migrations along the neritic zone during those periods and that in many cases new genera as well as new species arose suddenly without, apparently, having a genetic relationship to corresponding taxonomic units in other countries.

Since the assumption that the early Salina eurypterids lived in a "lagoon more or less cut off from the sea," leads to such difficulties, we must seek another theory. Let us assume that they lived in the rivers, and draw the logical deductions. It has been shown from their lithogenesis that the Pittsford and Shawangunk deposits must have been derived from Appalachia, while the Bertie was derived from Atlantica. Rivers, whether existing at the same time or at different geological periods, would carry related forms if coming from the same continent, but unrelated or only distantly related forms if coming from two different continents. Thus the Pittsford and Shawangunk eurypterids would be near relatives to say the least; while the fact that the larval forms from the latter are merely the young of those from the former is all the more according to our expectations.[3] Likewise the absence of close relationship between the Shawangunk and the Bertie,

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[3] It should be noted here that the adult individuals of the Shawangunk were preserved only as unrecognized fragments, the young forms alone, by virtue of their small size, escaping the destruction which was meted out to their progenitors, as was discussed on p. 101.

and with one exception between the latter and the Pittsford, is easily understood and entirely to be expected. The baffling break in the phylogenetic history of Stylonurus is also explained. First found in the Pittsford, it came from Appalachia; on that continent its evolution continued through the remainder of Siluric time, its remains not being found because the continental, chiefly river flood-plain, deposits from Appalachia during the Upper Siluric and the Lower Devonic are unknown on the North American continent. The perplexities which were so detrimental to the "lagoon" theory are completely removed by the river theory. But if the latter be accepted, a new objection arises—only one, to be sure, yet at first it seems to demolish the theory altogether. How does it come to pass that *E. pittsfordensis* so closely resembles *E. lacustris* as to seem almost certainly the direct ancestor? In specimens approximately the same size the two species are found to be almost identical in the proportions of the cephalon (i.e., length: width = 2 : 3), and in the position and shape of the eyes. On the other hand, the posterior portion of the cephalon flares out in *E. pittsfordensis* or at least broadens out in a hyperbolic curve, while *E. lacustris* is marked by the nearly parallel sides of the cephalon. *E. lacustris* is not so broad a species as *E. pittsfordensis*, but otherwise does not differ especially in form. The telson in the latter species is unusually long, being nearly equal in length to the rest of the postabdomen.

An immature, but complete individual in the Buffalo Society of Natural Sciences Museum measures as follows:[4]

	mm
Length of head	21
Length of body	68
Length of telson	57
Total length	146

In another specimen which is incomplete, the telson measures 11.5 cm., while in *E. lacustris*, in an individual of about the same size, it measures only 6.5 cm. In spite of these differences, however, the species are very much alike, though not so closely related as *E. lacustris*, *E. remipes*, and *E. fischeri*, which can be understood from the fact that the three latter belong to the same horizon, while the former precedes them by a long period. I am quite prepared to agree with Clarke and Ruedemann that *E. pittsfordensis* is the an-

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[4] These measurements were kindly furnished to me by Mr. Henry R. Howland.

cestor of the Bertie forms. Not only this; it actually came from the same region as the later types. For it must be apparent that the rivers of Atlantica, which furnished the deposits of the Bertie, were also in existence during Pittsford time and must have mouthed into whatever remnant there was of the Niagaran sea. It is not particularly likely that the ancestors, if so we may call them, of the Upper Siluric rivers occupied precisely the same location as the Bertie or Herkimer rivers, but undoubtedly they existed in somewhat the same general region. Therefore, what is more likely than that during Pittsford time these southward-flowing rivers from the continent of Atlantica should bring down the remains of organisms living in them? These rivers could not themselves have supplied the muds of the Pittsford shales, for they came from a limestone region, and whatever sediments they carried must have been of the nature of waterlimes. If such calcareous deposits were spread out on the flood plains of those rivers they are now no longer visible, for subsequent erosion has removed all traces of deposits of Pittsford age in Canada; but there is where a eurypterid fauna would be expected to occur, just as in Bertie time when waterlimes were deposited farther south the fine eurypterid fauna is found. This explanation makes it entirely clear why *E. pittsfordensis* is related to no form yet known from the Shawangunk, but has characteristics showing that it was ancestral to forms in the Bertie. New discoveries have corroborated this theory.

Professor C. J. Sarle has discovered the Pittsford fauna at a new locality in New York State. The details of this have not yet been published, but it is known that both *Eurypterus pittsfordensis* and Hughmilleria are common. The rock is a gray shale and the material was undoubtedly supplied by the rivers of Appalachia. Since Hughmilleria is otherwise known only from deposits derived from Appalachia it is reasonable to assume that the same rivers which carried in the muds also brought in the Hughmilleria. The abundance of *E. pittsfordensis* is not surprising, for if the rivers from Atlantica emptied into the Pittsford basin there is no reason why they should not bring as abundant a fauna as did those from Appalachia. If, as is to be expected, the basin in which these deposits were laid down was at times a fresh water lake, the eurypterid faunas of both river systems may have met and lived for a time in this water body. They were then killed by the sudden incursion of the Guelph sea which brought with it the remnant of the Guelph fauna found in the intercalated limestone.

Further corroboration is offered by Van Ingen's discovery in Oneida county already referred to. In the concretionary block obtained from that locality and determined from lingulas and orbiculoideas in it to come from dark gray shales with intercalated waterlimes and dolomite beds 21 feet below the base of the red Vernon shale,[5] were found three carapaces and fragments of a eurypterid, which Clarke and Ruedemann have named *Eusarcus vaningeni*. They state that "the outline of the body . . . . the visual surface . . . . . the appendages, so far as seen, are like those of *E. scorpionis*. The tergites and sternites have the form and relative dimensions of *E. scorpionis*. . . . . The ornamentation is that of *E. scorpionis*, but the scales are smaller and more clearly arranged" (39, 420, 421). It is also somewhat related to *E. cicerops* from the Shawangunk, but the relation is generic rather than specific. That this species of Eusarcus, more closely related to a species in the Bertie than to a contemporary species in the Pittsford, should be found in the waterlime facies of the Pittsford rocks in a region but a few miles distant from the mouth of the subsequent Herkimer river, is a most unusual corroboration of our theory. It is exactly what could have been prophesied. How such an occurrence is to be explained on the lagoon theory is puzzling.

If the river hypothesis is the correct one it must account for the migration of the eurypterids from the Buffalo region to the Baltic during the Salinan or early Monroan. If we assume the existence of two rivers flowing from the rather low and flat limestone-covered country to the north, into a sea which had its shore extending through New York, as indicated on the map (fig. 8), it would not be difficult to understand that the shed exoskeletons of arthropods inhabiting the waters of these rivers and occasionally dead or even living individuals would be carried down stream, and become embedded in the fine lime sediment of the two neighboring deltas or in the interstream areas. Probably the eurypterids themselves were seldom carried down to the debouchures, since it is their molted exoskeletons which are generally found. To account for the similarity of the Buffalo and Herkimer faunules, it is necessary to postulate the interfingering of the headwaters of the Bertie and Herkimer rivers. The physical and faunal conditions would then be analogous to those existing at the present time in the Columbia and Missouri rivers, as outlined on

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[5] I shall refer to these shales hereafter as the Farmer's Mills shales, from the locality near which they were found.

p. 205 above. If we assume such a mode of distribution by rivers for the eurypterids, it would explain the close relationship which exists between forms isolated, but in neighboring localities; that is, *Eurypterus lacustris* of the Buffalo area, and *E. remipes* of the Herkimer area, nearly related species, but occurring in two isolated localities. But besides, these two occurrences, the river hypothesis must account for the close relation of both of these species to the one in the Baltic region (see below p. 235). There is good stratigraphic reason for believing that in Siluric time there was a continental mass (the Atlantica of Grabau), which as already outlined occupied much of the present North Atlantic and extended from northern North America entirely across to eastern Europe. According to Walther, several high mountain chains extended across this land connection (**294**, 251), and undoubtedly large rivers came down from these. Their headwaters would very probably interlace, as do those of all large rivers on the various continents at present.

Under such conditions we can see that the common ancestor of *Eurypterus lacustris*, *E. remipes* and *E. fischeri* could have lived in the headwaters of one of those rivers, and that getting farther away from the point of origin, the various species derived from it would be differentiated. *E. lacustris* and *E. remipes* were developed in two neighboring streams, but the forms connecting *E. remipes* and *E. fischeri* which must have lived in the rivers of Atlantica, are now buried under the waters of the North Atlantic Ocean. The more distant relationship of these species suggests that there were intermediate forms, though these have not yet been found, and are probably nowhere preserved, though it is not impossible that Siluric strata with such intermediate species may exist beneath the ice cap of Southern Greenland. In this great system of rivers, which to all appearances characterized the continent of Atlantica, the Bertie and Herkimer Rivers were not very far apart, so that the faunules of each were very similar. In fact, the deltas spread out at the mouths of the two rivers may have become confluent in their outermost or seaward portions, though the waterlime now known would, as above explained, represent only the inshore facies. It may have happened that in times of flood the river waters flowed out over a broader area near the debouchures until some of the distributaries became for a time confluent, thus allowing some of the species from one river to be carried over into the area of deposition of the other. Thus might the presence of *Pterygotus cobbi* in both regions be accounted for.

The Upper Siluric Faunas of the Baltic Region. Let us next consider the fauna from Oesel, Gotland, and the Baltic provinces of Russia. On Oesel three species and two varieties of eurypterids are known: *Eurypterus fischeri* Eichwald, *E. fischeri* var. *rectangularis* Schmidt, *E. laticeps* Schmidt, *Pterygotus osiliensis*,[6] Schmidt, and *P. osiliensis* var. *laticauda* Schmidt. From Gotland the same Pterygotus species is reported, but no Eurypterus has yet been found. In Podolia a few specimens of *Eurypterus fischeri*, fragments of *Pterygotus osiliensis* occur, and Schmidt reports a few broken pieces of shell referable to the latter species in Galicia. From Livland, *Pt. osiliensis* has been reported by Eichwald. It is thus seen that in the Baltic Isles and West Russian provinces three species and two varieties of eurypterids occur. The close similarity, approaching identity, of *Eurypterus fischeri* to *E. remipes* and *E. lacustris* from the Bertie has been dwelt on at length (p. 230 above); the variety *E. fischeri rectangularis* naturally has its closest affinities with the Bertie forms. Schmidt described *E. laticeps* from two carapaces and did not compare it with any other form. There is no species in the Siluric fauna of Great Britain to which it shows any relationship, and so far as I am aware it cannot be compared with any other European form; but it shows considerable resemblance to *E. microphthalmus* from the Manlius waterlime. The largest specimen of the latter species measures 30 mm. long by 45 mm. wide, while one of the two known carapaces of *E. laticeps* shows corresponding measurements of 40 mm. and 60 mm., the ratio in both cases being as 2 to 3. The form of the eyes corresponds quite closely in the two species, but whereas in *E. microphthalmus* the distance between the eyes is almost equal to that between the eye and the lateral margin, in *E. laticeps*, on the other hand, the eyes are more widely spaced so that the distance between the eyes is one and a half times as great as between each eye and the margin (Schmidt, **248,** 63). No ornamentation has been observed on the carapace of *E. microphthalmus*, but on *E. laticeps* a series of black dots occur in rather regular arrangement between the eyes, extending forward toward the frontal margin and posteriorly a shorter distance. Since both of these species are as yet so little known, it is not safe to draw conclusions as to their relations. The fact of chief interest is that the Baltic form is more closely related to the Manlius

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[6] While it is not the intention of the author of this paper to revise or emend any generic or specific appellations of other authors except in so far as is necessary in the discussion of the problem at hand, it is advisable to call attention to the fact that *Pterygotus osiliensis* belongs to the subgenus Erettopterus established by Huxley and Salter for the Pterygoti which have bilobed telsons.

species than to any other. There remain the specimens of *Pterygotus osiliensis* and its variety, *laticauda*.

In the lower beds of the Old Red sandstone are two species of Pterygotus, *bilobus* and *anglicus* to both of which *P. osiliensis* shows some similarity, though the stronger affinity is to the latter of the two from Great Britain. A comparison of Schmidt's restoration of *P. osiliensis* and of an actual specimen of *P. bilobus* var. *inornatus* (fig. 22), brings out the similarity in general form, the correspondence of the telsons especially in their bilobate character, the agreement between the pincers and the arrangement of teeth in the chelae, the similarity in the shape of the carapace and in the size and form of the swimming paddles. The abdomen of *P. bilobus* is not so narrow nor so gracefully tapering as is that of *P. osiliensis;* the proportions of the carapace likewise differ, that of the former species being longer than

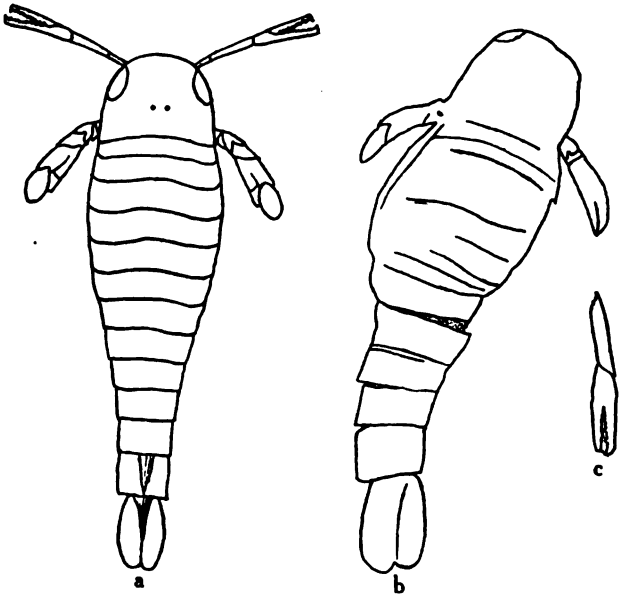

FIG. 22A. *Pteryogotus osiliensis* SCHMIDT. RESTORATION
(After Schmidt. 1883, p. 72, fig. 1 A)
FIG. 22B. *Pterygotus bilobus* VAR. *inornatus* (SALTER). × ½.
(After H. Woodward. 1878, pl. X, fig. 1)
FIG. 22C. CHELA OF SAME SPECIES. ×½.
(Ibid. fig. 2)

that of the latter. The similarities, however, are pronounced, and it is not to be denied that *P. osiliensis* finds its nearest relative in *P. bilobus*. Aside from this species, there are several others belonging to the subgenus Erettopterus, and we cannot dismiss our comparative study without calling attention to them. They are: *Pterygotus* (*Erettopterus*) *grandis*, and *globiceps* from North America; but they are so very distinct from the Baltic form that genetic relationship is in no way indicated.

The variety *laticauda* of *P. osiliensis* is founded not without certain misgivings on the part of Schmidt for an exceptionally large metastoma and a similarly large telson found associated with the *P. osiliensis* specimens. So far as the present problem of the determination of the relations between faunas is concerned, this variety would be classed along with *P. osiliensis*, and needs no separate discussion.[7]

The species of faunas of the Upper Siluric waterlimes of Oesel, Gotland, Livland, Podolia, and Galicia are thus seen to show very close relationship either to species in the Bertie waterlime, as in the case of *Eurypterus fischeri*, and var. *rectangularis*, or to species found in Great Britain at the end of the Siluric or the beginning of the Devonic. That is, they show affinities to the faunas occurring in deposits which for reasons other than faunal ones were judged to have been derived from the continent of Atlantica.

The Fauna of the Wenlock. There now remains only the discussion of the eurypterid-bearing deposits of Great Britain, (6) the Wenlock of Scotland, and (7) the Old Red sandstone. In the Wenlock beds there is a large fauna represented by at least twelve determinable species of eurypterids, and one would expect to be able to attain to some critical knowledge of the relationship of the forms there occurring to those in North America and Europe; but while the fauna lacks not in the number of species and of individual remains, complete or even nearly complete specimens are not to be found, and one is forced to attempt to draw conclusions concerning relationships from fragments of legs, carapaces, or body segments, an attempt which is not only difficult but altogether unsatisfactory because of the probable errors attending it. Let us, however, consider the species

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[7] The author, however, questions the propriety of the creation of a new variety for the two specimens found. Undoubtedly the metastoma which Schmidt cites is larger than the two which he considers belong to the typical *P. osiliensis;* on the other hand, it is only slightly larger than would be required to fit with the operculum or with the thoracic segment which he figures on Plate V, figs. 1 and 3. The three metastoma are so similar in form and ornamentation that it seems rather dangerous to use mere variation in size, particularly when that is so expectable, and when various parts of the body indicate a species of no mean dimensions.

seriatim, bearing in mind that details in structure are in most cases unavailable and that consequently genetic relationships are obscured. Of the genus Stylonurus, three species have been described by Laurie: *S. elegans*, *S. macrophthalmus*, and *S. ornatus*. The first species has been placed by Clarke and Ruedemann into the subgenus Ctenopterus, together with *S. cestrotus* Clarke, and *S. multispinosus* Clarke and Ruedemann; the former from the Shawangunk, the latter from the Pittsford, the subgeneric characters being the relatively greater length of the second and third pairs of legs when compared to the first, and the presence on the former of more than two pairs of long, slightly curved spines, which are vertical on the lower side of the segments (Clarke and Ruedemann, **39**, 286–287). The Scottish species is so different from the two American forms grouped with it that the author is tempted to take exception to their being placed in the same subgenus, particularly because the very characteristics which are mentioned as diagnostic are not always observable. My reasons for objecting to the subgeneric grouping of this form under *Ctenopterus* are as follows: (1) It is unsafe to base a taxonomic group of such great value as a subgenus upon the characteristics of one set of organs alone, as for instance, the legs. Nothing at all is known of the body of *S. multispinosus* and very little about that of *S. elegans;* only that of *S. cestrotus* having been found in good enough preservation to allow of restoration. (2) Single identical morphological characters do not of themselves establish specific relationship and, therefore *a fortiori* they cannot be used to unite their possessors into groups of higher taxonomic value for it is a law of palaeontology which is coming more and more to be recognized, that the same morphological characters crop out in many diverse phyletic groups and their presence in no wise indicates genetic relation. Thus, a modification in the proportions of the legs or in the number of spines cannot be considered characters of subgeneric rank. (3) The length, breadth, general form and grouping of the spines on the second and third pairs of legs are not at all similar in *S. elegans* and *S. cestrotus* (fig. 23). The comparatively short spines of about equal length, regularly spaced, and projecting at almost right angles from the walking legs, in *S. excelsior* (provided the restoration of this species is correct) and in *S. cestrotus*, together with the greater length in the second and third pairs of legs as compared with the first pair, might allow of these two species being placed in the same subgenus, and with them quite probably *S. multispinosus*. *S. elegans*, however, is too distinct, it seems to me, to be considered even subgenerically related, while specifically this species must certainly stand alone. This is especially evident when we consider (4) That one of the two diagnostic characters of the subgenus Ctenopterus depends upon the comparison of the lengths of the first three pairs of legs, the particular comparison being made between the first, and the second and third pairs, but in *S. elegans* the first pair is unknown.

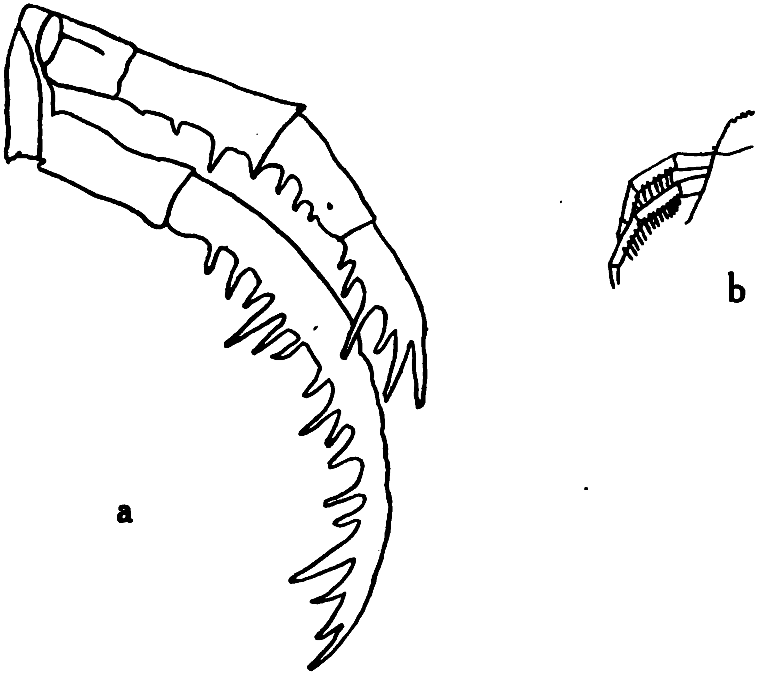

FIG. 23

a. Stylonurus elegans Laurie. Second and third legs on right side. (After Laurie, 1900, pl. II, fig. 12.)

b. Stylonurus cestrotus Clarke. Second and third legs on left side. (After Clarke and Ruedemann, 1912, pl. XLIX, fig. 4.)

Stylonurus ornatus and *S. macrophthalmus* are in some respects quite closely related to species occurring in the later Scottish horizons in connection with which they will be spoken of again. Here it is sufficient to note that there are no North American species which have the characters of the genus Stylonurus (sens. str.) namely, the first three pairs of legs relatively short and stout, with only two short, curved spines on each segment, as in Drepanopterus and Eurypterus.

From the Wenlock, Laurie has also described three species of Eurypterus: *E. conicus*, *E. minor* and *E. cyclophthalmus*. These are three small species which are not very well represented and which are primitive or retarded in development. They are not related to any American forms nor do they appear to fill ancestral positions, for the British species of the Upper Siluric and Devonic. In some one characteristic a Wenlock species seems to foreshadow a later one, but phyletic lines are difficult, if not impossible, to trace. The exceedingly large eyes in the single known specimen of *E. cyclophthalmus*, and in *E. conicus*, and the small size as well as the general form suggest that these two species are larval forms. Clarke and Ruedemann consider that *E. minor* also is either immature or has had its development arrested. They think that such is especially the case in *Bembicosoma pomphicus* Laurie, a small, stunted form with large head, rapidly tapering body, and "warty texture of skin."

The genus Drepanopterus Laurie is now placed by Clarke and Ruedemann as a subgenus of Stylonurus. To this group belong Laurie's three species: *D. bembicoides*, *D. lobatus*, and *D. pentlandicus*, which need not be discussed in detail since they show no affinities either to American or to continental European forms. The species described by Laurie as *Eurypterus scoticus* has since been revised by Clarke and Ruedemann who recognized its affinities to Eusarcus. In the American faunas it finds its nearest representative in *E. scorpionis* from the Bertie. Because of the impossibility of making accurate measurements of the proportions of different parts of the bodies and of obtaining exact outlines to show the form, one is unable to make careful comparisons.

The only remaining species in the Wenlock eurypterid fauna is *Slimonia dubia* Laurie, a small individual, much broken and without appendages. Laurie has included in this species a second individual which shows a portion of the telson. Since the genus at present comprises only two species, the one just mentioned, and *S. acuminata* from the Ludlow, there is no opportunity to trace relationships over broad areas. The main reasons for making a new species of the Wenlock Slimonia, were, the difference in geologic age between the two forms, and the fact that the Pentland Hills individual was gradually tapering instead of abruptly contracted in the seventh segment into a telson.

Summary of the Wenlock Fauna. A survey of the entire eurypterid fauna of the Wenlock of Scotland must be made with the realization beforehand that all of the material is so fragmental, dismembered, macerated, and poorly preserved that detailed descriptions, accurate measurements, and unimpeachable determinations are things beyond the power of anyone to obtain, and that, furthermore, until discoveries of new faunas at earlier horizons in Great Britain shall be made, the ancestry of the Wenlock species must remain obscure. Many new genera appear suddenly in this Lower Siluric horizon, and we are unable to do more than say that such and such genera came from a common ancestor. It is unfortunate, indeed, that the Ordovicic of Great Britain has not yielded such faunas as it has in America. Yet, keeping these points in mind, we are still struck by the provincial character of the Wenlock fauna. There is not a species in it which is closely related to any of the North American species except *Eusarcus scoticus* which foreshadows in certain respects *E. scorpionis* from the Bertie.

The Fauna of the Ludlow. The Ludlow of Lanarkshire has yielded nine species of eurypterids. *Slimonia acuminata* Salter has just been mentioned in connection with *S. dubia*, the two being very similar. *S. acuminata*, Clarke and Ruedemann state, "has all the features of a local and aberrant type," (**39**, 130). *Pterygotus* (*Erettopterus*) *bilobus* with the four varieties: *acidens*, *crassus*, *inornatus*, and *perornatus* is found abundantly at Lesmahagow, the last variety, however, being very rare. As was pointed out in the discussion of the Baltic provinces faunas, there is closer relationship between *P. bilobus inornatus* and *P. osiliensis* than there is between either of these forms and a species in any other fauna (p. 238 above). *Stylonurus logani* belongs to the revised Stylonurus *sens. strict.*, having the second and third pairs of legs short, thick, and with two pairs of spines in each segment (see Woodward, **312**, 131). There are no known species on any other continent to be compared to this form which is not even very much like any of the Wenlock species, with two of which it agrees in its subgeneric characters, but with neither of which it has specific similarities. Indeed, it is quite unlike *S. macrophthalmus* which is characterized by the peculiar ear-shaped epimeral expansions, the long parallel-sided metastoma, the rounded cephalon, and very short second pair of legs. It is a little more like *S. ornatus* which has a slightly more squarish cephalon than *S. macrophthalmus*, and which has not such pronounced ears on the epimera, although these are extended posteriorly to a much more pronounced degree, than in *S. logani.*

The only species which has epimera approaching in size and form those of *S. macrophthalmus* is *S. scoticus* from the Old Red sandstone (see p. 251 below), from which, however, it differs in certain important features. It is closest to a second species found in the Old Red sandstone, *S. powriei,* which it resembles in the tapering form of the body the long, narrow telson, the subquadrate outline of the head (this is decidedly square in *logani*) and in the great length of the fourth appendage. In details, on the other hand, these two species differ considerably, so that *S. logani* must remain a rather separated species until new discoveries reveal its relatives. It is of great interest to have reported from the Ludlow fish bed in one of the tributaries of Greenock Water (see p. 164 above), *Stylonurus ornatus* associated with the typical Lanarkian (Downtonian) fishes and with *Eurypterus dolichoschelus,* a Ludlow and Lanarkian species, together with Ceratiocaris, Dictyocaris, plants, etc. (p. 164 above). *S. ornatus,* then, evidently persisted from Wenlock into and through Ludlow time. In this case one is again confronted with an anomalous geographic and geologic distribution. The Pentland Hills are less than thirty miles distant from the Lanarkian inliers, and the two areas are approximately on the same line of strike. In two thin beds but a few inches in thickness and extending only a few yards laterally *S. ornatus* occurs in the Wenlock in Lanarkshire; but in the Pentland Hills this species occurs in none of the many Ludlow eurypterid horizons until the fish bed is reached and there a few specimens are found. If the eurypterids lived in the Wenlock sea as they are commonly supposed to have done, then the supporters of this view must account for the limited vertical and horizontal distribution of the merostome remains, since it is absolutely inconceivable that members of a marine neritic fauna should be confined to an area a few square yards in extent. It is equally inconceivable that a marine fauna should be perpetuated for so great a period of time as from the Wenlock through the Ludlow, the members of the later fauna in some cases showing resemblance to members in the earlier, while in others they are entirely distinct and apparently arise suddenly, there being, besides, no indications of a persistent marine stock to furnish decendants from the Wenlock fauna, nor yet any trace in the marine Ludlow of the incursion from other regions of new genera and species of eurypterids. Moreover, we can not understand why one species of the Wenlock recurs in the Upper Ludlow, but does not occur in the beds of intermediate age, although there are many such with good marine molluscan faunas and even with fragments of other eurypterid species. Such a perpetuation, to repeat, would be impossible if the eurypterids were not having a continuous existence in the sea. But their remains are at all times spasmodic in appearance, being altogether wanting in certain horizons, especially where the typical marine fauna is abundant. The fact that they occur in a given band which, when traced even a short distance laterally, shows no lithological change, but only an absence of eurypterids, indicates that migrations along shore were non-existent; while the fact that new species and even new genera appear at horizons far separated from underlying and overlying eurypterid horizons seems to deprive "marine" eurypterids of ancestors or descendants, while to account for a marine *Stylonurus ornatus* in the Wenlock of Lanarkshire and in the uppermost Ludlow of the Pentland Hills, is not within the inventive powers of the author. But, on the other hand, the conditions of bionomy in rivers are eminently satisfactory to account not only for the persistence of a species for a long period of time without morphological modifications of specific rank, but also for the development of new species and genera, and for their sudden appearance. This takes place, because they have been developing either in other river systems, whence they have migrated to the headwaters of the river at the mouth of which their remains are found, or because they have been traversing a great distance in longitude, automatically suffering specific variation in their progress. In this way, would I account for the anomalies in distribution just dwelt upon (see also p. 203 et seq.).

Of this Ludlow fauna there still remain four species to be considered. There are three species of Eusarcus which may be taken up at the same time: *E. scorpioides*, *E. obesus*, and *E. raniceps*. The last species may be quickly dismissed, since it is represented by a single specimen showing only the carapace and a part of the abdomen, enough, indeed, to place the individual generically; but specific comparisons are impossible. *E. scorpioides* is represented by one almost entire individual, a large, robust form in many respects similar to *E. scorpionis* from the Bertie waterlime. The length and width of the appendages, the number and disposition of spines thereon, the ratio of length of carapace to the remainder of the body, and the proportions generally agree in the two species. Even more like *E. scorpionis* is the single known specimen of *E. obesus* from the same Lesmahagow horizon, and it has been suggested by Woodward, who described the species, that *E. obesus* may possibly represent the young of *E. scorpioides;* certainly *E. obesus* looks very much like a young individual of *E. scorpionis* figured by Clarke and Ruedemann from the Bertie (Figs. 24 and 25). Thus there is close relationship between the two species from Lanarkshire and the one from the Bertie.

The last species from the Ludlow fauna, and the only Eurypterus yet found therein is *E. lanceolatus* Salter. As Sarle, Clarke, and Ruedemann have pointed out, this species has many points in common with Hughmilleria and either belongs to that genus or is transitional to it. The form of the body, shape of the carapace and of the telson, marginal position of the eyes, the relative proportions of the somites, and details in the appendages, all point to affinities with *Hughmilleria socialis* Sarle, from the Pittsford (figs. 26, 27). Such a relationship seems a little disconcerting at first, in view of the fact that the Pittsford sediments and fauna came from Appalachia, while the Ludlow was a derivative from Atlantica and should have a fauna essentially distinct from the former. Indeed, with the exception of this one species, the members of the Ludlow fauna show no relationship to any species from the faunas of Appalachia. We have here, as a matter of fact, one of the "anomalies" of distribution

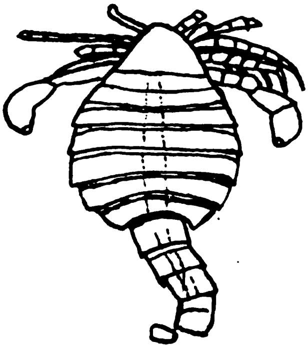

FIG. 24. *Eurypterus obesus* H. WOODWARD. $\times \frac{9}{10}$
(After Woodw. 1878, pl. XXX, fig. 8)

FIG. 25. YOUNG OF *Eusarcus scorpionis* GROTE AND PITT. $\times \frac{1}{3}$
(After C. & R. 1912, pl. XXXVI, fig. 1)

which may occur among fluviatile organisms, but are inexplicable for marine forms. In the upper Niagaran in North America *H. socialis* occurs by the hundred in the Pittsford shale and the closely related *H. shawangunk*, which may be only the young of the former species, occurs in the synchronous shales of the Shawangunk, but in no other part of the world at that time, so far as we know, were there any representatives of Hughmilleria. It appears that the genus originated in the rivers of Appalachia. Curiously enough, in the Upper Ludlow, that is, lower Upper Siluric, of Scotland, *Eurypterus lanceolatus* appears, showing a striking resemblance to *Hughmilleria socialis*. The prolific Scottish fauna of the Wenlock has revealed no possible ancestors for this distinctive Eurypterus (or Hughmilleria?) and one naturally wonders how it arose. Since Hughmilleria was restricted in occurrence in the Niagaran, any migrations which took place must have been effected during the Salina period. The important Salina

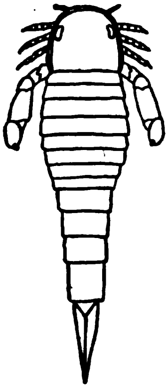

FIG. 26. *Eurypterus lanceolatus* SALTER. × ½.
(After Woodw. 1878, p. 142, fig. 44)

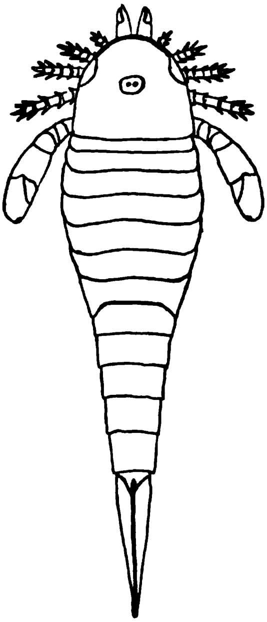

FIG. 27. *Hughmilleria socialis* SARLE × ½.
(After Cl. & R. 1912, pl. LIX, fig. 1)

break or period of emergence has recently been recognized by Grabau as affecting all countries bordering on the North Atlantic and has been recorded for North America, Scotland, Oesel (by the author), and even in what was formerly supposed to be the continuous section in England (89B). There was a widespread diastrophic movement at the end of the Niagaran marking a broad expansion of continental areas during Salina time so that perhaps nowhere are there preserved to us the marine sediments of that period. Certainly the North American eurypterids were cut off from marine routes of migration with which most authors like to provide them, and yet migration seems to have gone on. The Salina in North America was a period of aridity west of the mountain mass of Appalachia, but that chain died out northward and probably merged into the continent of Atlantica, there being no northeast Atlantic sea-lobe at that time. Several possible lines of fluviatile migration were open and nothing is more probable than that emigrants from Appalachian north and northeast flowing rivers should have entered some one of the tributaries of the systems on Atlantica. The exact mode of transit can not be determined, but many routes were open. Indeed, it is possible that migration occurred even in Pittsford time from the rivers of Appalachia into one of the Pre-Bertie rivers which we have seen probably existed in the western New York region even during the Niagaran (p. 113 above). This much we may conclude: There were many routes and possibilities of migration open to eurypterids living in the rivers of Appalachia during the Lower and Middle Siluric, but continuous marine paths to Europe were non-existent. Furthermore, the distinctness of the Ludlow fauna as a whole from any of the faunas of Appalachia, but the close relationship of *one species* from the former to two from the latter is inexplicable for members of a marine fauna, but normal and expectable for members of fluviatile faunas.

The Old Red Sandstone Fauna. The last of the European formations which is believed to have been derived from the continent of Atlantica is the Old Red sandstone. Most the eurypterids occur in the beds in various localities in Forfarshire. By far the most abundant species is *Pterygotus anglicus* which finds it nearest relatives in *Pterygotus buffaloensis* and *P. macrophthalmus* from the Bertie, and *P. osiliensis* from the Baltic region. The various points of similarity are so well known that it is not necessary to take them up. *Pterygotus minor* is a small form found associated with *P. anglicus*, but it is a unique form, and shows a marked divergence from congeneric forms throughout the world. The telson is elongate, spatulate, with a pronounced median keel, which is represented on the last three segments of the postabdomen as a long spine, rather than a ridge (Woodward, **312,** 199, Pl. X, fig. 2; 195, p. 35, Pl. I, fig. 4). There can be little doubt that this species, which is represented by a single, nearly entire individual, represents a neanic stage of some form, the adult of which probably is not known. Only two and a half inches long, it has the large eyes slightly removed from the border, a feature which is so characteristic of neanic Pterygoti; but it is difficult to account for the pronounced spines on the body segments, and for the high keel, features, which in associated species are less developed at so early a stage. The shape of the carapace and the position of the eyes suggest *P. macrophthalmus* from the Bertie, but the spines on the epimera of the last five segments of the postabdomen, the median spine on the last three, the very marked median keel on the telson as well as the proportions of the telson indicate a specialization far beyond that observable in the species just mentioned, particularly when it is borne in mind that all of these features are observed in an undoubtedly young individual, which means that they would be much more marked in maturity. This species has all of the appearances of an aberrant form, the relations of which it is impossible to determine from the one known specimen, but it certainly has characters which unite it with Bertie species and with forms which occur in the Baltic region.

The Stylonuridæ of the Old Red sandstone are represented by four species: *S. scoticus*, *S. powriei*, *S. ensiformis*, and *S. symondsii*. The first, represented only by a head and by one nearly entire individual, is yet so remarkable, so entirely distinct from the typical Stylonurus that it has been set apart by Clarke and Ruedemann as the representative of a new subgenus, Tarsopterus. These two authors have dwelt upon what they consider the close similarity between *S. scoticus* and *S. myops* from the Shawangunk, stating that "it seems probable, therefore, that *S. myops*, when fully known, will prove a representative of the subgenus Tarsopterus of which *S. scoticus* is the type" (**39,** 303). The reasons which they cite are: occurrence of "spurlike epimera of equal relative size," the "outline of carapace," and "the approximate position of the eyes and the sculpture of the tergites." Since it is my purpose in the present section of this paper to marshal all of the evidence provided by the relationship existing between the genera and species of different faunas in order to determine from which continents these were derived, it is evident that a claim of close similarity between a species in the Shawangunk fauna, derived as I believe from Appalachia, and a species in the Old Red sandstone derived from the continent of Atlantica, as I hope to prove, must be carefully investigated. Therefore, I proceed to the points enumerated, always bearing in mind that certain types of similarity are of more value than others. In the beginning I may state that *S. myops* is known only from immature specimens, most of which are carapaces alone, and that only one entire specimen has been found and this is but 55 mm. in length (see pl. 52, fig. 6, Clarke and Ruedemann). The largest carapace of *S. myops* observed measured 19 mm. in length by 27 mm. in width; the only carapace of *S. scoticus* known measured 16 cm. in length and 19 cm. in width; the single, entire individual known measured 3 feet, 4 inches in length. A most profound difficulty arises at once, namely, that of comparing neanic and nepionic specimens of a mid-Siluric species with a gerontic, or perhaps a late ephebic individual of the Lower Devonic. But granting that such comparisons are possible or even allowable, let us turn to the characters which would justify placing these two species in the same subgenus. First, there is the outline of the carapace. It must be admitted even by Clarke and Ruedemann that, with all due allowance for compression, the carapaces of *S. myops* display a most unusual amount of variation in outline, some, were it not for the position of the eyes, being easily referable to Eurypterus. The carapaces show a strong tendency to grow narrower posteriorly, showing the greatest width in the anterior third, whence the lateral margins slope gently backwards; the nearly parallel sides shown in the carapace of *S. scoticus* are usually not present in *S. myops*, while the frontal

SPECIES	LENGTH OF CARAPACE IN MM.	BREADTH OF CARAPACE	RATIO: LENGTH: BREADTH
S. myops, smallest carapace observed	3.5	5.5	0.63
S. myops, type	12.3	16.5	0.74
S. myops, largest carapace observed	19.0	27.0	0.70
S. macrophthalmus (Ludlow)	51.0	61.0	0.83
S. powriei	50.0	62.0	0.80
S. scoticus (separate carapace)	160.0	190.0	0.84
S. scoticus (carapace attached to body)	204.0	242.2	0.83

margin is quite as likely to be curved as to be nearly flat (as in *S. scoticus*). A comparison of the proportions of length to breadth of carapace in these two species and in two others with which relationship might more readily be established will, when taken in connection with the illustrations, show that *S. scoticus* in so far as its carapace is concerned, is far more nearly related to associated forms in the Old Red and to others in the Ludlow, than to the Shawangunk forms.

From these figures we may conclude that Clarke and Ruedemann find the approximate ratio of length to breadth of carapace in *S. myops* to be as 2 : 3, but it is evident that in *S. scoticus* it is 4 : 5. It is not to be denied that the ratio changes from that in the young of *S. myops* where it is 2 : 3 to that in the type where it is nearly 3:4, and perhaps it might be conceded that in larger forms the ratio might approach 4 : 5; but we cannot be sure. There is in the Ludlow, however, a species which has a carapace proportioned exactly as in *S. scoticus* and even in the Old Red is a species, *S. powriei*, with proportions almost the same. Thus there is no need to form conjectures about what might be possible relations to a Middle Siluric species from Appalachia when there are forms which actually show the similarity in formations derived from the same land-mass.

A second point of supposed similarity between *S. scoticus* and *S. myops* was the occurrence of long and pronounced epimera in both species. I have in another part of this paper discussed the significance of spinous prolongations on the epimera, but I shall call attention to the arguments again, since they are not universally recognized. Beecher has assembled a wealth of illustration from all branches of the animal kingdom to show that the appearance of spines as a modification of any morphological character marks degeneration in respect to that character, and, when extreme spinosity is accompanied by certain other easily recognizable and similarly degenerate characters the species, genus or family, all members of which show like degeneration, is doomed to decline and extinction. But not only that; as Beecher, Hyatt, and a few present-day palaeontologists, notably Grabau, have shown and have demonstrated by countless illustrations which have led to the most certain deductions, the formation of spines is a homeomorphic character, not in the least indicative of genetic relationship in forms which develop such spines, but marking only an onto- or phylogenetic stage. Spines may and do appear in end-members of totally distinct phyletic groups and are of absolutely no diagnostic value in determining true relations. The Eurypteridae offer many new illustrations of this law which is so simple, which so strongly makes its appeal to the reason, and which yet is so constantly ignored. The Carbonic species of Eurypterus develop spines wherever possible; the surface scales are produced into pointed wedges or spines; the ends of the epimera grow out to a great length; spines develop on the appendages not only in rows along the various segments but also on the lines of junction between segments: showing that the final expression of morphological characters in the eurypterids was the development of spines which was followed by extinction. Such a development has seemed expectable to many authors for the species living in the late Palæozoic, in the Mississippic, and Carbonic; but there is really nothing to prevent these phylogerontic characters from appearing much earlier. And so, to apply all of these general statements to the case in question, I would say that the epimeral spines observable on *S. myops* indicate that the line which that species represented was on the decline even in the Siluric, at a time when the majority of eurypterids were at their acme. A glance at the illustration of *S. scoticus* (Woodward 312, Pl. XXII) will show to the reader that this species has a typically gerontic appearance. Its epimeral prolongations do not in the least resemble those in *S. myops*, but are most like those of *S. macrophthalmus* from the Ludlow.

Two points remain as supposedly indicative of relation between these two species. The position of the eyes is, it seems to the author, the only feature of marked similarity, but certain of the British forms also show such a position, so that it is not of striking importance. As for the ornamentation of the tergites, I can see little to warrant the statement that the sculpture is similar in the two species.

The species *Stylonurus* (*Tarsopterus*) *scoticus* has now been compared in detail with *S. myops* and it has been shown that they are not closely related and consequently the presence of the first genus in the Old Red sandstone not only does not militate against my thesis that the faunas living in rivers coming from the same continent and in the same latitude should be most alike, but it is actually an additional proof, for *S. scoticus* is most nearly related to Ludlow and Old Red species, though it shows phylogerontic characteristics which somewhat obscure its relations.

The three remaining species of Stylonurus from the Old Red may be quickly dismissed. *S. symondsii*, from England, is represented by a single apparently complete carapace which is almost as long as wide, but is distinctly narrower posteriorly than anteriorly. There is a possibility that the marginal fold has been destroyed in the posterior portions, but Woodward thinks that the specimen is entire, and that the fold did not pass all the way around the carapace. *S. ensiformis* is described from a single broken tail spine which, it seems to the author, is hardly sufficient for the founding of a new species, and certainly is of no use in determining the affinities of the fauna. *S. powriei*, represented by a single individual, has a carapace very similar in form and identical in proportions to *S. scoticus*, from which species it differs most noticeably in having the last pair of appendages long and tapering, not short and broad. Woodward has suggested that it probably had epimeral prolongations which have not been preserved, because only the internal mold in sandstone has been found, and the epimera would be likely to remain with the actual integuments; for the same reason none of the surface markings are visible. The tail is extremely long and narrow, quite similar to the telson of *S. logani* from the Ludlow, which form it also resembles in the character of the last pair of appendages. Both species belong to the provisional group of Stylonurus s. st. recognized by Clarke and Ruedemann.

Completing the Old Red sandstone fauna are two species of Eurypterus: *E. brewsteri* and *E. pygmaeus*. The first consists of a carapace, a portion of a thoracic segment slightly displaced, and an ovisac containing more than twenty ova (Woodward, **312**, 151). Woodward says that "this species agrees most nearly in general form with *E. lacustris*" from the Bertie, while Clarke and Ruedemann have pointed out a close similarity to *E. microphthalmus* from the same horizon (**39**, 195). But since both authors make their comparison on the form, proportions of length or width, and position of eyes, and since the actual figures do not support either statement, I find it impossible to agree with them.

	LENGTH OF CARAPACE	WIDTH	RATIO L:W
	mm		
Eurypterus brewsteri	1.48	5.52	0.27
E. lacustris	44.00	63.00	0.70
E. microphthalmus, type	15.50	22.00	0.70
E. microphthalmus, best preserved specimen	17.5	27.40	0.64

E. pygmaeus is a small form found near Kington, England, and though represented by very young individuals, yet has characters which point to its affinities with *E. remipes* (Fig. 28).

SUMMARY OF FACTS OF DISTRIBUTION ON CONTINENT OF ATLANTICA. We are now enabled to bring together all of the many lines which we have been following in tracing the affinities of the faunas which for other reasons were supposed to have come from the continent of Atlantica, and here, as in the case of the faunas of Appalachia, the great weight of evidence shows that the Bertie, Rondout, Manlius, Ludlow, Lanarkian, Baltic, and Old Red faunas are more closely related inter se than they are to the faunas which from the study of the petrogenesis of the formations in which they occur, were believed to have come from other continents.

THE EURYPTERID FAUNAS OF MISSISSIPPIA. So far only a single fauna is known from the continent of Mississippia, and therefore it is not possible to institute any comparisons between the species found in that fauna and those from other faunas on the same continent, as was possible in the case of Atlantica and Appalachia; the most that can be expected is that we shall find the Kokomo eurypterids distinct from all those which lived in rivers on other continents. As we shall see, the theoretical expectations are fully borne out by the facts.

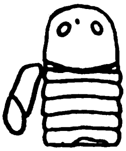

FIG. 28. *Eurypterus pygmaeus* SALTER. × 1
(After Woodw. 1878, pl. XXVIII, fig. 5)

The Eurypterid fauna of the Kokomo waterlime is distinct from any of the known North American eurypterid faunas. The material is never well preserved and the number both of species and of individuals is small. "*Stylonurus* (*Drepanopterus*) *longicaudus*," says Clarke and Ruedemann, "is a unique form among the American eurypterids being the sole representative thus far found on this continent of this rare and phylo-genetically interesting genus. From its Scottish allies, it is readily distinguished by its slender and elongated postabdomen and the long, clavate telson." (**39**, 320) Four specimens are known, two young and two mature individuals, and though they are in sufficiently good condition to enable Clarke and Ruedemann to make a restoration of the species, they do not approach the perfection of preservation found in the Bertie material. The characters are clearly enough shown to make it a certainty that this form has no relatives in the American faunas, so far known. Five specimens of *Eusarcus newlini* are known. This species, though attaining the gigantic size of *E. scorpionis* of the Bertie, shows marked differences in the proportions of the body. There is a general shortening up and broadening throughout. A set of figures taken from Clarke and Ruedemann's discussion will bring out this fact; some of the figures are only approximate.

Lengths in millimeters

	CARAPACE	PREABDOMEN	POSTABDOMEN	LAST POST ABDOMINAL SEGMENT	TELSON	RATIO OF CARAPACE TO REST OF BODY
E. scorpionis	53	67	146	40	62	0.17 : 1
E. newlini	58	57	112	34	43	0.23 : 1

It will be noted from these figures that although *E. newlini*, in the specimen measured, had a carapace 5 mm. longer than that of *E. scorpionis* the remainder of the figures for the other portions of the body are considerably less, showing that the proportions throughout are different. The ratio of the length of the carapace to the length of the rest of the body in the two species shows that in *E. scorpionis* it is as 0.17 : 1, while in *E. newlini* it is as 0.23 : 1. The cephalothoracic appendages are much stouter in *E. newlini*, with longer and stouter spines. Since the Bertie and Kokomo species of Eusarcus are the only ones in this country which are well enough preserved to allow of careful description, they are the only ones which can be compared and it has been shown that they do not show close relationship. The Kokomo fauna has yielded further two species of Eurypterus which are very similar, namely, *E. (Onychopterus) kokomoënsis*, and *E. ranilarva*. Of the difference between these two species Clarke and Ruedemann say: "It is possible that these differences are only those of sex, a point that at present cannot be determined since the opercular appendages of *E. ranilarva* are not distinctly shown" (**39**, 211). The proportions between the length and width of the cephalon in the Kokomo and Bertie forms are quite different. In *E. ranilarva* the ratio is as 7.1 : 10; in one specimen of *E. kokomoënsis* it is as 8 : 10, in another as 8.4 : 10, but in *E. dekayi* the ratio is only as 6 : 10 in one specimen and is even as low as 5.3 : 10 in another.

From these figures it appears that the Kokomo forms had cephala which were much more nearly square than rectangular. A set of comparative figures for the proportions in the different parts of the three species brings out the differences clearly.

Lengths in millimeters

SPECIES	CARAPACE	PREABDOMEN	POSTABDOMEN	TELSON	RATIO OF CARAPACE TO REST OF BODY
E. dekayi	31	40.4	56.0	53.0	20.7 : 100
E. ranilarva	35	40.0	50.0	35.0	27.8 : 100
	33	43.5	41.5	36.0	27.0 : 100
E. kokomoensis	28	32.3	43.4	30.4	25.9 : 100

The same relations hold here between the body proportions of the Kokomo and Bertie species as held in the case of Eusarcus. A comparison of the figures for *E. dekayi* and the first specimen of *E. ranilarva* shows that though the carapace of the latter is longer, all of the other parts of the body are shorter. Thus, the Eurypterus species as well as the one of Eusarcus are relatively shorter and broader forms than the ones found in the Bertie.

The Kokomo eurypterid fauna as a whole is quite distinct from any other American fauna, a fact which is difficult to explain on the theory of marine habitat for these organisms. If, as Clarke and Ruedemann have stated, the Kokomo is of Lockport age, and belongs to the marine fauna of that time, it is greatly to be wondered at that there should be no eurypterid fauna in the succeeding Guelph beds in the same locality or in adjoining regions. Yet the only Guelph form that has ever been found is the single specimen of *Eurypterus* (*Tylopterus*) *boylei* from Ontario, a form which shows not the slightest resemblance to any of the Kokomo eurypterids. If the Kokomo is to be considered of Monroan age, for reasons which have been given in full on p. 118 then, on the marine theory, the Kokomo forms should show relationship to the Bertie, and their area of deposition should constitute merely another "pool" cut off from the Monroan sea. But it has just been shown that the Kokomo fauna is quite distinct from the Bertie and that the two faunas have no species in common, a fact difficult to explain on the ground that the forms lived in neighboring "pools" where faunas were segregated from a once widespread marine fauna.

On the other hand, these peculiarities are easily understood, if we consider the eurypterids as fluviatile organisms. It is quite evident that the Kokomo deposits have a distinctly different source from those of the Bertie. If then, these eurypterids belong to a distinct river system, developed upon a separate land mass, it would indeed be surprising if they were not wholly distinct specifically from those of the rivers of Atlantica which were responsible for the Bertie waterlime deposits. The alternation of beds with marine fossils with beds carrying only eurypterids and ceratiocarids, suggests that the Kokomo deposits may have approached those of some modern estuaries in which we have an alternation of marine and fresh-water deposits. The map, Fig. 8, shows the position and general extent of these late Siluric river systems.

CONCLUDING REMARKS

When the significance of the distribution and of the occurrence of the eurypterids is given its full importance, there can no longer be any doubt that the eurypterids at *no* time of their known history were normally marine organisms. We cannot conceive of marine animals presenting such localized occurrences and yet having such wide distribution as a class. The question of transit seems not to have been considered by previous authors, and yet it is one of the greatest importance. If we suppose that the eurypterids lived in the Palæozoic rivers, we have furnished them with the proper milieu for individual as well as racial development. For we must not overlook the fact that when these animals make their appearance in numbers, they are already highly differentiated. To a river dweller migrations from the headwaters of one river system to those of another are easily possible, and this is the only way by which we can account for the distribution of these organisms, unless we assume migrations along continuous shore lines which is, however, negatived by the lack of remains in the shore deposits of the period in which they most abound. Furthermore, the segregation into "pools" can be accounted for only by assuming that these "pools" were fed each by its own river system. A candid and unbiased survey of the facts presented cannot but lead to the unqualified belief in the fluviatile habits of these remarkable arthropods of the Palæozoic era of the earth's history.

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ABBREVIATIONS USED

Abhandlung d. k. k. geol. Reichsanstalt.—Abhandlung der kaiserlich-koeniglichen geologischen Reichsanstalt.
Am. Geol.—American Geologist.
Am. Jour. Sci.—American Journal of Science.
Am. Nat.—American Naturalist.
Ann. Soc. Geol. Belgique.—Annales de la Société Géologique de Belgique.
Ann. and Mag. Nat. Hist.—Annals and Magazine of Natural History.
Archiv für d. Naturk. Liv.- Ehst.- und Kurlands,—Archiv dür die Naturkunde Liv-. Ehst-. und Kurlands.
Beitr. zur. Pal. u. Geol. Oest.-Ung. u. d. Orients.—Beiträge zur Palaeontologie und Geologie Oesterreich-Ungarns und des Orients.
Brit. Ass. Adv. Sci.—British Association for the Advancement of Science.
Bull. Acad. Imp. d. Sci. St. Petersbourg.—Bulletin de l'Academie Impériale des Sciences de St.-Petersbourg.
Bull. Am. Mus. Nat. Hist.—Bulletin of the American Museum of Natural History.
Bull. Buf. Soc. Nat. Sci.—Bulletin of the Buffalo Society of Natural Sciences.
Bull. G. S. A.—Bulletin of the Geological Society of America.
Bull. Min. and Met. Soc. Am.—Bulletin of the Mining and Metallurgical Society of America.
Bull. Soc. Geol. France.—Bulletin de la Société Géologique de France.
Bull. Soc. Imp. Nat. Moscou.—Bulletin de la Société Imperiale des Naturalists de Moscou.
Can. Nat. & Geol.—Canadian Naturalist and Geologist.
Denk. d. k. Akad. d. Wiss.—Denkschriften der Kaiserlichen Akademie der Wissenschaften.
Geol. Mag.—Geological Magazine.
Jour. Geol.—Journal of Geology.
Mem. Acad. Imp. d. Sci. Saint-Petersbourg.—Memoires de l'Academie Impériale des Sciences de Saint-Petersbourg.
Mem. Geol. Surv. United Kingdom.—Memoirs of the Geological Survey of the United Kingdom.
Mem. Soc. Geol. France.—Memoires de la Société Géologique de France.
Monatsber. d. d. geol. Ges.—Monatsberichte der deutschen geologischen Gesellschaft.
Neues Jahr. Min. Geol. Pal.—Neues Jahrbuch für Mineralogie, Geologie and Paläontologie.
Proc. Am. Acad. Arts and Sci.—Proceedings of the American Academy of Arts and Sciences.
Proc. A. A. A. S.—Proceedings of the American Association for the Advancement of Science.
Proc. Am. Phil. Soc.—Proceedings of the American Philosophical Society.

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[1] Through the efficient coöperation of Miss M. F. Wilson, Librarian of the Geological Department of Columbia University, and of her assistant Miss Hepburn, I have been able to consult every one of the references in the following bibliography.

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Trans. Geol. Soc. Penn.—Transactions of the Geological Society of Pennsylvania.
Trans. G. S. Lon.—Transactions of the Geological Society of London.
Trans. N. Y. Acad. Sci.—Transactions of the New York Academy of Sciences.
Trans. Roy. Soc. Can.—Transactions of the Royal Society of Canada.
Trans. Roy. Soc. Edin.—Transactions of the Royal Society of Edinburgh.
Verh. d. Russ.-kais. min. Gesell. St. Petersburg.—Verhandlungen der russisch-kaiserlichen mineralogischen Gesellschaft zu St. Petersburg.
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BY

L. HUSSAKOF, PH.D. AND W. L. BRYANT

INTRODUCTION

The Buffalo Society of Natural Sciences possesses a collection of fossil fishes numbering several hundred specimens. This collection includes materials from many different localities, but by far the larger part of it consists of specimens from the immediate vicinity of Buffalo. As regards these, it is the largest collection ever brought together, and as such is invaluable to students of the geology or the fish life of the Devonic of western New York and the neighboring region.

But notwithstanding the great interest of the collection, it has never been described, and only a few of the specimens have been studied by paleontologists. In this catalog, therefore, we propose to describe and illustrate this collection, and thus make it available for scientific purposes to all students of the vertebrates. We hope also that by directing attention to the rich fossil fields in the vicinity of Buffalo, this catalog may be the means of stimulating the interest of local collectors so that specimens may continue to accumulate and make possible some day the solution of a number of interesting problems suggested by these primitive forms, which for the present must remain partly, if not wholly, unsolved.

A word in regard to the method of treatment adopted in this catalog. Our primary concern is with individual specimens rather than with species. Our aim is to describe and figure these specimens so that they may become scientifically available to all, and not merely to those having access to the collection. This, it seems to us, is after all the chief function of a catalog of this kind. Hence discussions of species, except in so far as the specimens in hand throw new light upon them, are not extensively gone into. And synonymies are omitted except in the few cases where it is necessary to indicate the reasons for a proposed change in nomenclature, or to epitomize the history of some little known, or lately proposed, name.

We wish here to express our grateful acknowledgments to Mr. Henry R. Howland of the Buffalo Museum, for his kindly interest in this work, and for the help and encouragement given us during the long period it has been in preparation. It has seemed to us especially fitting, as a permanent memorial of Mr. Howland's relations to this work, that his name be linked with one of the new forms represented in the Buffalo Museum; and we have accordingly proposed for one of the most interesting species from the vicinity of Buffalo, the name *Ptyctodus howlandi*.

SOURCES OF THE MATERIALS

The specimens in the collection are derived from several different sources, as follows:

1. A series of specimens from various horizons and localities, more especially from the Upper Devonic in the vicinity of Buffalo, which forms the nucleus of the collection. This part of the collection has grown up gradually in the course of the past three decades or longer, as a result of the geological and paleontological excursions in the vicinity of Buffalo by members of the society, as well as through the occasional gifts of specimens by various friends.

Of first importance in this connection are the collections made by Mr. F. K. Mixer of Buffalo, long a member of the society and at one time the curator of the museum. Mr. Mixer did pioneer work in investigating the Devonic fish-bearing formations in the vicinity of Buffalo, and to his zeal are due some of the most noteworthy specimens in the collection, particularly those from the Rhinestreet shale at Sturgeon Point, on the shore of Lake Erie. Mr. Mixer has kept alive the knowledge of these localities, and has counseled all investigators—as both of the present writers well remember—seeking to collect in the region about Buffalo. It was he who guided Mr. Bryant to the locality at Sturgeon Point, and thus made possible the continuation of the work which he had himself so well begun.

Here also belongs a fine series of specimens from the Hamilton of Wisconsin, presented by Mr. Edgar E. Teller formerly of Milwaukee, now of Buffalo. Then there are a number of specimens which were presented by J. S. Newberry, most of them with labels in his own handwriting, and therefore especially valuable. There are some shark teeth from the phosphate beds of Florida, presented by Ottomar Reinecke; a number of fossil fish remains collected by John F. Carll on the second Pennsylvania survey, acquired by the Museum several years ago; and a few interesting specimens from Devonic horizons near Buffalo, collected and presented by Prof. Clifton J. Sarle.

2. A magnificent collection of fish remains from the rocks in the vicinity of Buffalo, brought together during the past four years by Mr. William L. Bryant. This collection more than trebled the entire fossil fish collection previously in the museum, and is the largest collection extant of specimens from the Devonic formations of New York State.

3. A series of fish remains collected by Mr. Bryant on a short trip to the Chemung of Pennsylvania, in 1913.

4. A small but valuable series of sharks and dinichthyids collected by Mr. Bryant from the Devonic shales near Cleveland, Ohio, in August, 1914.

5. A suite of specimens collected by Mr. Bryant from the Devonic rocks at Scaumenac Bay, Quebec, in 1915.

GEOLOGICAL FORMATIONS IN THE VICINITY OF BUFFALO

The city of Buffalo is very favorably situated with regard to formations containing fossil fishes. There are more than a dozen localities within fifty miles of Buffalo, over half of which may be reached by electric cars running out of the city. All are of Devonic age. A few hours' collecting at any one of these localities, is almost certain to yield some specimens.

The following table of geological formations will be useful in locating the relative position of the fossil fish horizons referred to in the catalog.

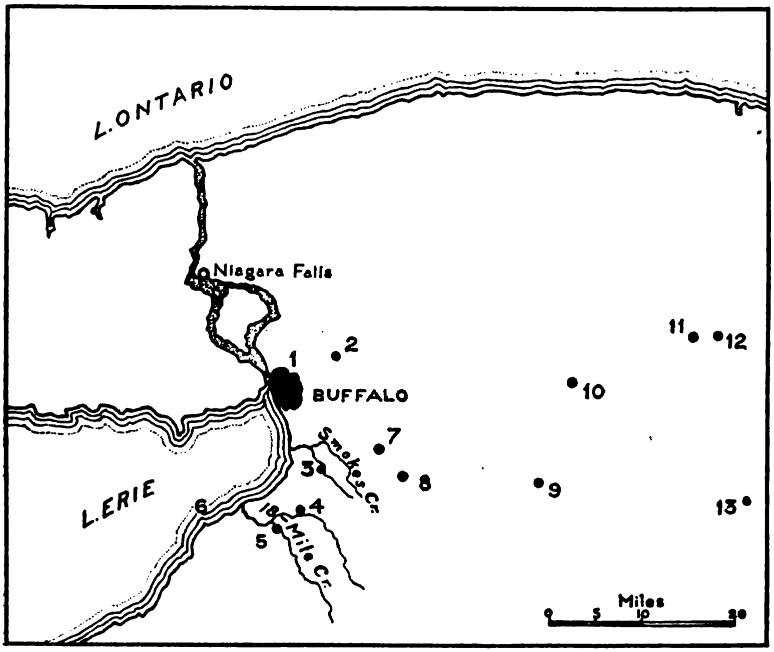

Fig. 1. Fossil Fish Localities Within 50 Miles of Buffalo

1, Buffalo—northeastern city limits; *2*, Williamsville; *3*, Windom; *4*, Hamburg; *5*, North Evans; *6*, Sturgeon Point; *7*, Springbrook; *8*, Cazenovia Creek at East Aurora; *9*, Varysburg; 10, Alexander; *11*, Leroy; 12, Lime Rock; *13*, Mt. Morris.

MID DEVONIC FORMATIONS

Onondaga Limestone

At the northeastern limits of the city of Buffalo, and along the road to Leroy, there are a number of limestone quarries, some of them very extensively developed. These quarries are of Onondagan or Mid Devonic Age. An interesting series of fossil fish remains has been obtained from them, among which the following species can be identified. The most remarkable form among them is that represented by the curious dental plates, ornamented on the outer face

*The Devonic System in New York State with Special Reference to the Formations in the Vicinity of Buffalo**

	GROUPS	STAGES	FORMATIONS NEAR BUFFALO
Upper Devonic	Chautauquan	Chemung [Catskill = local facies]	
	Senecan	Portage	Wiscoy shale Laona sandstone Gardeau shale Dunkirk shale Hanover shale Angola shale Rhinestreet shale Cashaqua shale Middlesex shale
		Genesee	West River shale Genundewa limestone (*Styliola*) Conodont bed Genesee shale
		Tully	Pyrite layer
Mid Devonic	Erian	Hamilton	Moscow shale Tichenor limestone Ludlowville shale Skaneateles shale
		Marcellus	Cardiff shale Stafford limestone Marcellus shale
	Ulsterian	Onondaga Schoharie grit	Onondaga limestone
Lower Devonic	Oriskanian	Esopus grit Oriskany beds	
	Helderbergian	Port Ewen limestone Becraft limestone New Scotland beds Coeymans limestone	

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*The classification into groups and stages is that of Clarke and Schuchert ("The nomenclature of the New York series of geological formations:" *Science*, n.s., x, 874–878, 1899), with some modifications introduced later by Director J. M. Clarke in the bulletins and memoirs of the New York State Museum.

The formation names are those used in a recent paper on the geology of Erie County by Frederick Houghton (*Bull. Buffalo Soc. Nat. Sci.*, xi, 1–92, 1914).

with closely crowded tubercles, described on a subsequent page of this catalog as a new genus of ptyctodont, under the name of *Deinodus*.

Macropetalichthys rapheidolabis Norwood & Owen
Acanthaspis armata Newberry
Eczematolepis fragilis (Newberry)
Arthrodire indet. [fragmentary plates]
Machæracanthus major Newberry
Deinodus bennetti, n. gen., n. sp.
Onychodus sigmoides Newberry

This is a typical Onondagan fauna, with all the more important species known from other Onondagan formations, for instance, the Delaware limestones of Ohio. It should be remembered, however, that the Onondaga of New York is not exactly coeval with the Delaware limestones of Ohio; and that, therefore, the faunas cannot be expected entirely to correspond. This accounts for the presence in the Buffalo Onondaga of such a form as *Deinodus*, and its absence from the Ohio formations; or the absence from the New York horizon of some forms present in the former.

Marcellus and Hamilton

The Erian Group, including the Marcellus and Hamilton stages, is well represented in the vicinity of Buffalo, although not so extensively developed as at some other localities in New York State. Fossil fishes are extremely rare in these formations. In the vicinity of Buffalo only a single species has been obtained from them in many years of collecting by various investigators. This species is *Machæracanthus longævus* Eastman, the type of which is from the "Trilobite bed" (lower portion of the Hamilton), near the mouth of Eighteen Mile Creek.

UPPER DEVONIC FORMATIONS

The other fish bearing formations near Buffalo are of Upper Devonic Age—Tully, Genesee and Portage. The most fruitful localities are: (1) along the shore of Lake Erie, near Sturgeon Point, about 15 miles west of Buffalo (fig. 1); and (2) on Eighteen Mile Creek, near the villages of North Evans and Hamburg, N. Y. From these two localities the bulk of the Buffalo collection has been derived.

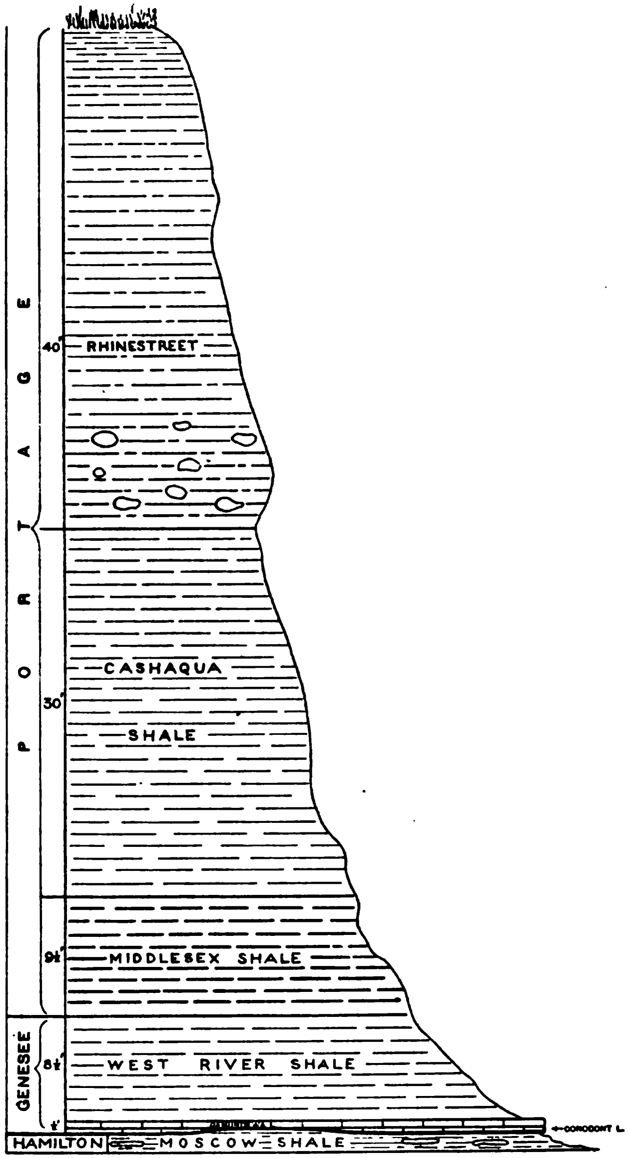

Fig. 2. Section on Eighteen Mile Creek, Showing Exposure of the Upper Devonic Formations

The thicknesses are those given by A. W. Grabau in his paper, "The faunas of the Hamilton Group of Eighteen Mile Creek and vicinity." (*16th Ann. Repl. State Geologist, N. Y.*, 231–339, 1899; especially p. 240.) The formation names are the ones used by F. Houghton in his paper "The geology of Erie County." (*Bull. Buffalo Soc. Nat. Sci.*, xi, 1–92, 1914.)

Tully Pyrite Layer

The Tully limestone is absent in Erie County, but on Cazenovia Creek, near Springbrook, a bed of solid pyrite, 4 or 5 inches thick and underlying the black Genesee shale, apparently marks the Tully horizon.

Dental plates of two species of fishes occur in this bed, both belonging to the Ptyctodontidae: *Ptyctodus compressus* Eastman and *Palaeomylus*, sp. Besides these there are undetermined Pleuracanthid shark teeth, perhaps belonging to the genus *Dittodus*.

Conodont Bed[1]

(Pls. 2 and 3)

So many of the specimens described in this catalog are from the Conodont bed, that this formation needs to be discussed in some detail. The Conodont bed is a layer of limestone about four inches in maximum thickness, constituting the base of the Genesee in certain sections on Eighteen Mile Creek. It lies immediately below the Genundewa (*Styliola*) limestone, and is best exposed in a few sections near the railroad bridge at the village of North Evans in Erie County. In typical exposures, it thins out in both directions and may, therefore, be regarded as occurring in lenticular patches. The name "Conodont bed" was proposed as long ago as 1879, by G. J. Hinde, the designation having been suggested by the abundance of Conodonts in some parts of the formation.[2]

Lithologically, the Conodont bed is an impure limestone containing large numbers of quartz grains, small pebbles, crinoid stems, fragments of fossil wood, and other matter. Here and there are fragments of pyrite and more or less broken remains of fishes and invertebrates. The fishes were first recorded by Hinde, who wrote concerning them as follows:

"In addition to the Conodonts, there are in this same bed numerous fragments of Crinoid stems, *bones and plates of undetermined fishes, and teeth closely resembling, if not identical with, those of Ptyctodus.*"[3]

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[1] A preliminary account of the Conodont bed fauna was presented by the authors before the Paleontological Society, at the Philadelphia meeting, December, 1914. Abstract in *Bull. Geol. Soc. Amer.*, vol. 26, p. 154.

[2] "One particular band of the limestone (near the village of North Evans), which I purpose to designate the Conodont-bed, is filled with fragments of these small teeth." (*Quart. Journ. Geol. Soc.*, London, xxxv, 352, 1879.)

[3] Ibid., p. 353. Italics are ours.

But although fish remains were known to occur in this formation so long ago, they were practically not represented in collections until they were rediscovered a few years ago by Mr. Bryant. Since then he has visited the locality at frequent intervals and has made a considerable collection of specimens, and on one occasion both authors of this catalog visited the locality together for the purpose of collecting.

The mode of occurrence of the fossils, in places where they are abundant, is well illustrated in figure 3. This represents a slab of limestone 11 by 18 inches, which contains 21 specimens of fossils and fragmental material. The remains are, however, not equally abundant throughout the bed. They seem to have become piled up in some places, while at others they are almost absent. Here and there one may encounter an almost complete fish plate.

The following is a list of the species at present known from the Conodont bed:

Arthrodira

Coccosteus sp.
Dinichthys magnificus, n. sp.
Dinichthys newberryi Clarke
Dinichthys pustulosus Eastman
Dinichthys insolitus, n. sp.
Dinichthys sp. [numerous isolated plates]
Stenognathus denticulatus, n. sp.
Stenognathus insignis, n. sp.
Perissognathus aduncus, n. gen., n. sp.
Machærognathus woodwardi, n. gen., n. sp.
Copanognathus crassus, n. gen., n. sp.
Dinomylostoma buffaloensis, n. sp.
Dinomylostoma sp. [juvenile]
Aspidichthys notabilis Whiteaves
Acanthaspis, sp.

Incertæ Sedis

Holonema abbreviatum (Eastman)
Oëstophorus lilleyi ? (Newberry)
Eczematolepis fragilis (Newberry)
Arthrodires indet. [fragmentary plates]
Acmoniodus clarkei, n. gen., n. sp.

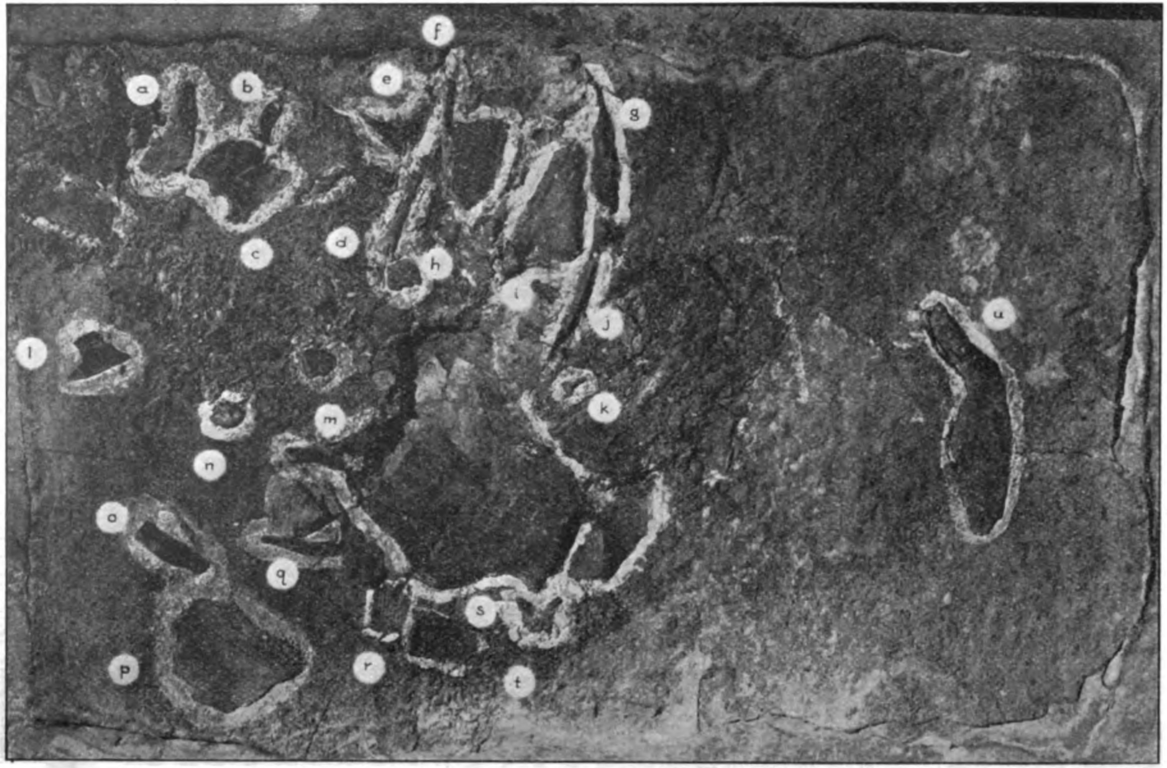

FIG. 3. A SLAB OF CONODONT LIMESTONE, 11 BY 18 INCHES, SHOWING THE ABUNDANCE OF FOSSIL REMAINS IN CERTAIN SPOTS IN THIS BED. TWENTY-ONE SPECIMENS ARE INCLUDED IN THIS SLAB.

a, Dinichthys insolitus; *b*, Ptyctodus compressus; *c*, Arthrodire plate; *d*, Orthoceras sp.; *e*, Symphyseal spine of Ptyctodont; *f*, Water-worn pebble; *g*, Ctenacanthus wrighti; *h*, Fragment of a mandible; *i*, Stethacanthus præcursor; *j*, Machæracanthus sp.; *k*, Imperfect tooth of Dittodus priscus; *l*, Beak of Ptyctodus howlandi; *m*, Tritor of Ptyctodus compressus; *n*, Water-worn pebble; *o*, Tritor of Ptyctodus howlandi; *p*, Suborbital of Dinichthys sp; *q*, Tritor of Ptyctodus compressus; *r*, Fragment of Ctenacanthus wrighti; *s*, External occipital of Dinichthys sp.; *t*, Dittodus priscus; *u*, Ptyctodus howlandi.

Ptyctodontidæ

Ptyctodus calceolus Newberry & Worthen
Ptyctodus compressus Eastman
Ptyctodus howlandi, n. sp.
Ptyctodonts indet. [plates and tritors]
Rhynchodus telleri, n. sp.
Rhynchodus ornatus, n. sp.
Palæomylus lunaformis, n. sp.
Palæomylus sp.
Dermal plates [gen. and sp. indet.]

Elasmobranchii

Cladodus urbs-ludovici Eastman
Acanthodia indet. [fin-spines]
Dittodus priscus (Eastman)
Dittodus striatus (Eastman)
Dittodus grabaui, n. sp.
Synthetodus calvini Eastman
Orodus devonicus, n. sp.

Ichthyodorulites

Anodontacanthus pusillus, n. sp.
Ctenacanthus wrighti Newberry
Ctenacanthus sp.
Gyracanthus sp.
Machæracanthus peracutus Newberry
Stethacanthus præcursor, n. sp.

Dipneusti

Dipterus gemmatus, n. sp.
Dipterus sp.

Crossopterygii

Onychodus sigmoides Newberry

Actinopterygii

Ganoid tooth [indet.]

Several interesting conclusions may be drawn from this list as well as from considerations of the character of the Conodont layer itself.

1. In the first place, we have here one of the most remarkable assemblages of fossil fishes known from any Devonic formation. It includes no less than 27 genera (not counting two or three[4] too fragmentary for identification) with about 40 species. It is therefore nearly as rich in species as the fauna of the Cleveland shale of Ohio, although the specimens are, of course, not to be compared with the latter in point of preservation. The fauna will also stand comparison in richness with any of the local facies of the Old Red Sandstone of Scotland, such as the Achanarras, the Orkney, or the Cromarty faunas; or with the remarkable fish fauna made known ten years ago by Jaekel, from the Upper Devonic at Wildungen, Germany.[5]

Apart from the large number of genera and species represented, the Conodont-bed fauna is remarkable for the presence of so many different groups. Nearly every division of fishes that existed in Upper Devonic times is represented—Sharks (all four divisions: Pleuropterygii, Ichthyotomi, Acanthodia and Euselachia); Arthrodira, Ptyctodontidæ, Ichthyodorulites, Dipneusti, Crossopterygii and Acanthopterygii.

2. Another remarkable feature about the Conodont fauna, is the large number of forms peculiar to it. Out of a total of 34 identifiable species, 15 are known only from this formation; the remaining 19 are represented by groups of fours, fives, or less, in several different formations. The latter species are mostly such as had a long geological history, some of them ranging through several successive formations, or had a very wide geographical distribution.

The following table shows the range of the fossil fishes common to the Conodont bed and other formations. As will be seen from this, 4 species are common to the Conodont bed and the New Albany shale. This is not surprising when we consider that both formations are of Genesee age. It may also be noted that the mode of preservation of the fossils and the character of the matrix of the New Albany shale is, in certain areas at least, similar to those of the Conodont bed. But it is surprising to find 6 species surviving from the Hamilton.

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[4] For instance, the Acanthodian represented by a fin-spine, and the extraordinary plates ornamented with broad parallel ridges, illustrated in figure 37, page 106.

[5] O. Jaekel: Neue Wirbeltierfunde aus dem Devon von Wildungen. *Sitzunsb. Gesell. Naturf. Freunde*, Berlin, 1906, 73–85, with 10 figures.

Geological Range of Conodont Bed Fishes Known to Occur in Other Formations

CONODONT-BED SPECIES	MID DEVONIC				UPPER DEVONIC					
	New York		Ohio	Wisconsin	New York		Ohio	Indiana—Kentucky	Iowa	Manitoba
	Onondaga	Hamilton	Columbus and Delaware limestones	Hamilton	Genundewa	Portage	Cleveland shale	New Albany	State Quarry	Upper Devonic
Dinichthys magnificus						×				
Dinichthys newberryi					×	?		?		
Dinichthys pustulosus				×				×	×	
Stenognathus gouldi(?)							×			
Aspidichthys notabilis										×
Holonema abbreviatum						×		×		
Oëstophorus lilleyi				×						
Acanthaspis (?) armata	×		×	×						
Eczematolepis fragilis	×		×	×						
Ptyctodus calceolus				×		×		×	×	?
Ptyctodus compressus									×	
Cladodus urbs-ludovici								×		
Dittodus priscus*										
Dittodus striatus*										
Synthetodus calvini									×	
Ctenacanthus wrighti		×								
Machæracanthus peracutus	×		×							
Machæracanthus longævus		×								
Onychodus sigmoides	×	?	×	×						

* Known hitherto only from a peculiar formation, of Upper Devonic age, at Elmhurst, Ill.

3. While the Conodont fauna is clearly of marine origin, as shown by the character of the rock, which is a limestone, and by the abundance of Conodonts, now generally regarded as the teeth of annelids, and hence belonging to the sea or the seashore, it is noteworthy that there are some forms, e. g., dipnoan dental plates, which are generally regarded as indicative of fresh-water. How can we explain this seeming disparity? The answer may be found in the peculiar character of the formation. From the broken and abraded condition of most of the remains, and from the presence of pebbles and other fragmental matter, we may conclude that this band of limestone was laid down close to shore, and that many of the remains were rolled and tossed before they finally came to rest on the bottom. On the authority of Dr. G. R. Wieland we may state that fragments of fossil wood have been found in the Conodont bed, which by their worn and abraded surfaces show unmistakably that they had been tossed about before they had settled to the bottom.

All the evidence points to the fact that the Conodont bed was deposited close to shore. On such a view we can readily explain the great abundance of Conodont teeth in the formation: we may conceive that the annelids they represent lived in shallow water, or, indeed, on the beach itself, and thus would be washed into the deposit near shore. It seems probable, also, that some of the remains, for instance the dipnoan dental plates, were carried down by a river which emptied close to the location of the Conodont bed sediments. It appears not unlikely that the Conodont bed was a sand-bar, or a series of sandbars, at times exposed to the air, and situated in close proximity to the mouth of a river. Such conditions would account for all the peculiar circumstances connected with this formation—(1) its occurrence in lenticular patches; (2) the broken and abraded condition of the fossils, as well as the admixture of pebbles and fragmental matter; (3) the abundance of Conodont teeth; (4) the presence of fragments of fossil wood; (5) the commingling of fresh-water with marine forms; and lastly (6) account for the great diversity of forms present.

Genundewa and West River (*Genesee*)

In the Genundewa (or *Styliola* layer), fossil fishes are rather rare despite the fact that the layer rests directly on the Conodont bed (where this is present), in which fossils are so abundant. There are only a few remains from this formation in the Buffalo museum. Among them is a small slab containing associated ventral plates of a small dinichthyid, perhaps *Selenosteus*; and a plate which seems referable to *Acanthaspis armata*.

From the West River shale, which overlies the Genundewa, only two specimens have thus far been collected—a plate of *Holonema abbreviata* (Eastman), and the impression of a mandible of *Dinomylostoma buffaloensis*. They came from a band of limestone a few feet above the Genundewa.

In addition to the above mentioned specimens, a *Gyracanthus* spine, representing a new species, was collected from a Genesee horizon near Canandaigua Lake, by Prof. Clifton J. Sarle, which is described on a subsequent page of this catalog.

Rhinestreet (*Portage*)

The Rhinestreet, or "Black Naples," shale is well developed in the vicinity of Buffalo, having a total thickness in Erie County of

185 feet. The best fossiliferous exposures are at Sturgeon Point on the shore of Lake Erie, and along Eighteen Mile Creek. A considerable suite of fossil fishes has been collected from this formation and is preserved in the Buffalo Museum. They were collected by Mr. F. K. Mixer, and, during the past few years, by Mr. Bryant.

The following is a list of the Rhinestreet species represented in the Buffalo Museum:

Euostracophori

Phyllolepis elegans, n. sp.

Arthrodira

Coccosteus parvulus, n. sp.
Coccosteus sp.
Dinichthys intermedius (?) [mandibles]
Dinichthys magnificus, n. sp.
Dinichthys tenuidens, n. sp.
Dinichthys sp. [ventral armor; indet. isolated plates]
Stenognathus dolichocephalus (Eastman)
Stenognathus ringuebergi (Newberry)
Stenognathus mixeri, n. sp.
Selenosteus sp.
Dinomylostoma sp. [juvenile]
Acanthaspis sp.

Incertæ Sedis

Arthrodire indet. [juvenile plates]

Elasmobranchii

Cladoselache eastmani Dean
Dittodus sp.

Ichthyodorulites

Atopacanthus dentatus, n. gen., n. sp.

Acanthopterygii

Rhadinichthys devonicus (Clarke)
Rhadinichthys antiquus (Williams)
Palæoniscid indet.

LIST OF NEW GENERA AND SPECIES DESCRIBED IN THIS CATALOG

NEW GENERA

	Page
Perissognathus (Arthrodira)	81
Machærognathus (Arthrodira)	83
Copanognathus (Arthrodira)	84
Deinodus (Ptyctodontidæ?)	123
Acmoniodus (Elasmobranch?)	151
Atopacanthus (Ichthyodorulite)	157

NEW SPECIES

Phyllolepis elegans	21
Coccosteus parvulus	29
Dinichthys magnificus	36
Dinichthys tenuidens	55
Dinichthys insolitus	53
Stenognathus insignis	73
Stenognathus denticulatus	71
Stenognathus mixeri	75
Perissognathus aduncus	81
Machærognathus woodwardi	83
Copanognathus crassus	84
Dinomylostoma buffaloensis	86
Ptyctodus howlandi	112
Rhynchodus telleri	116
Rhynchodus ornatus	117
Palæomylus lunaformis	119
Deinodus bennetti	123
Dittodus grabaui	147
Acmoniodus clarkei	151
Orodus devonicus	153
Anodontacanthus pusillus	156
Atopacanthus dentatus	158
Ctenacanthus nodocostatus	159
Gyracanthus sarlei	142
Stethacanthus præcursor	169
Dipterus gemmatus	170

SYSTEMATIC DESCRIPTION OF THE COLLECTION

EUOSTRACOPHORI[5a]

Genus **Phyllolepis** Agassiz

Until very recently this genus was known only by detached plates, and was one of the puzzles of paleichthyology. But the discovery of a nearly complete specimen showing the plates in natural association, has solved this puzzle. This remarkable specimen was in a collection obtained from an Old Red Sandstone quarry, at Dura Den, Scotland, which had been closed for several decades, but was reopened a few years ago by a committee of the British Association, for the purpose of obtaining a collection of the fossil fishes known to occur in it.

A preliminary account of the *Phyllolepis* specimen, with a figure, was published by A. S. Woodward in 1915 (Rept. Brit. Assoc. Adv. Sci., 84th Meeting, p. 122, pl. ii). His conclusion as to its affinities is as follows:

> The whole fossil is most suggestive of the ventral aspect of the curious Devonian Ostracoderms *Drepanaspis* and *Psammosteus*. It agrees with *Drepanaspis* in showing two principal median plates one behind the other, though in *Phyllolepis* they are more nearly equal in size. It corresponds with *Psammosteus* in exhibiting a prominent pair of lateral cornua at the hinder end of the series of small marginal plates, opposite the middle of the posterior median plate. It differs from both in lacking separate small tessellated plates. There is, therefore, not much doubt that *Phyllolepis* is a genus of Ostracoderms most nearly allied to the Drepanaspidæ or Psammosteidæ.

Phyllolepis elegans, n. sp.

(Pl. 32, fig. 2)

E 2438 *Type.*—An elliptical plate 5 by 11.5 cm.

Formation and Locality.—Rhinestreet shale (Portage); Forks of Cazenovia Creek, near E. Aurora, N. Y. Collected by W. L. Bryant.

Elliptical plates ornamented with parallel lines arranged concentrically around a point somewhat nearer one extremity of the plate than the other. Lines near the periphery a millimeter or more in width, becoming progressively finer toward the centre. Central por-

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[5a] The term *Euostracophori*, to include the Ostracoderms as commonly understood, minus the Antiarchi, was introduced by Hussakof in 1906. *Mem. Amer. Mus. Nat. Hist.*, IX, 135.

tion of the markings resembling a fingerprint, except that the lines are all discrete and do not join. In this central portion of the ornamentation, the lines parallel to the long axis of the plates are somewhat recurved inward toward the centre of the plate.

Remarks.—This species is represented by specimens of various sizes, of which the type is the largest that has come under notice. It is the second species to be described from America, the other being *P. delicatula* Newberry (*Paleozoic Fishes North Amer.*, p.97, pl. xix, fig. 11), from the Chemung of Pennsylvania, from which it differs especially in ornamentation.

The following specimens are all from the Rhinestreet shale (Portage), at Sturgeon Point, on Lake Erie. They were collected by Mr. F. K. Mixer.

E 2039 Small elliptical plate 60 by 25 mm.; finely striated, the striations following the contour of the edge.

E 2040 Striated elliptical plate, 95 by 30 mm. (broken).

E 2041 Small plate with fine striations running parallel to the margin, 55 by 35 mm.

PLACODERMATA

In this catalog we adopt the view that the Antiarchi, the highest division of the old group Ostracophori, and the Arthrodira, are related. It seems impossible that such a remarkable correspondence between the two groups in the arrangement of the armor of the head and front portion of the body; in the head in both being movable on the shoulder armor; in the agreement of the fundamental plan of the dorsal armor plates; and the correspondence down to details in the plan of the ventral armor, can be due to parallelism and not to relationship.[6]

In this work we adopt the following arrangement of these primitive forms:

Placodermata (McCoy, 1848).[7]

1. Antiarchi (*Bothriolepis*, *Pterichthys*, etc.).
2. Macropetalichthyida.
3. Arthrodira (*Coccosteus*, *Dinichthys*, etc.).

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[6] For a discussion of this subject see L. Hussakof: Studies on the Arthrodira. *Mem. Am. Mus. Nat. Hist.*, ix, 105–154, 1906, pls. xii, xiii; especially pp. 128–135.

[7] *Ann. and Mag. Nat. Hist.*, 2 ser., ii, 1–10, 1848.

I. Antiarchi

Genus Bothriolepis Eichwald

This is the best known genus among the Antiarchi, exquisitely preserved specimens showing the entire creature—with the unarmored part of the body, tail and two dorsal fins—having been found. These specimens come from the fine-grained Upper Devonic sandstone exposed on the north shore of Scaumenac Bay, Quebec, and were discovered and first made known by Prof. William Patten.[8]

In addition to *Bothriolepis canadensis*, there are three other species of the genus in North America—*B. nitida* and *B. minor*, from the Chemung and Catskill of New York and Pennsylvania; and *B. coloradensis* from the Upper Devonic of Colorado.

In the Buffalo Museum there are a large number of specimens of *Bothriolepis* representing two species.

Bothriolepis canadensis (Whiteaves)

E 2576 Specimen little crushed but lacking head, showing the greatest depth of the animal to have been about half its greatest width. The trunk of *Bothriolepis* was, therefore, deeper than indicated by current restorations.

Upper Devonic: Scaumenac Bay, Quebec. This and the following specimens collected by W. L. Bryant, 1915.

E 2352 Complete head and trunk, dorsal view.

E 2353 Head and trunk of large individual in dorsal view, showing sensory canals and well-preserved lateral appendages.

E 2354 Head and trunk of very large specimen, in dorsal view.

E 2355 Head and trunk, in dorsal view.

E 2356 Very young individual, in counterpart, showing complete head and trunk 12 mm. in length.

E 2357 Impression of visceral surface of anterior half of ventral armor.

E 2358 Anterior dorsomedian plate, in visceral view, showing median keel.

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[8] New facts concerning Bothriolepis. *Biol. Bull.*, vii, 1904. The evolution of the vertebrates and their kin. Philadelphia, 1912; *passim*.

E 2359	Antero-dorsomedian plate, in visceral view.
E 2360	Proximal portion of right arm showing articular process.
E 2361	Dorsal aspect of nearly complete individual.
E 2362	Average-sized specimen, in dorsal aspect.
E 2363	Complete head, trunk and appendages of immature specimen.
E 2364	Antero-dorsomedian plate.
E 2365	Postero-ventrolateral plate, in counterpart, from a concretion in sandstone.
E 2366	Median occipital plate from a concretion in sandstone.
E 2367	Posterior half of the plastron.
E 2368	Complete head and trunk.
E 2369	Complete head and trunk.
E 2577	Nearly complete individual, in dorsal view.
E 2578	Very young individual, in dorsal view.
E 2579	Very young individual, in dorsal view.
E 2580	Head and anterior half of trunk, showing dorsal and ventral aspects.
E 2581	Head and trunk, in dorsal view.
E 2582	Ventral armor, in visceral view.
E 2583	Head and trunk, in dorsal view.
E 2584	Nearly complete specimen, in ventral view.
E 2585	Head and trunk, in dorsal view.
E 2586	Large individual, in dorsal view.
E 2587	Large specimen, in ventral view.
E 2588	Head and trunk, in dorsal view.
E 2589	Head and trunk of very large specimen, in dorsal view.
E 2590	Dorsal aspect of small individual.

Bothriolepis nitida Leidy

E 2502 Articular plate of pectoral appendage. On the same piece of rock is a scale of *Holoptychius giganteus?* Ag.
Catskill; Seeley Creek, branch of Lambs Creek, Mansfield, Tioga County, Pa. Collected by W. L. Bryant, 1913.

E 2504 Fine impression of ventromedian plate, in external view. Other data same as preceding.

E 2501 Impression of imperfect right anterior ventrolateral plate. Catskill; Troy, Bradford County, Pa. Carll Coll.

E 2503 Cast of postero-dorsolateral, showing the sensory canal. Original in Philadelphia Academy of Sciences. Catskill; Bradford County, Pa. Sherwood Coll.

II. MACROPETALICHTHYIDA

Macropetalichthys rapheidolabis Norwood and Owen

The genus *Macropetalichthys* is known only by head shields; and the structure of these is not yet entirely understood. Three species are recognized, two from Europe and one from America. The last, *M. rapheidolabis*, is the best known one of the three, being represented by more or less well-preserved cranial shields in various collections, the best of them from the Delaware limestone (Onondaga) of Ohio. The crania have not been found associated with other remains in such a way as to make it certain that they belong together; and although a number of new specimens have been obtained in recent years, nothing of importance can be added to what is already known regarding this form. The structure of the head shield was discussed by Eastman in 1897;[9] and the interesting history of the discovery and study of this genus was given by the same author in 1908.[10]

In the Buffalo museum there are several specimens, but none of them throws any additional light on the structure of this form.

E 1865 Fragment of a cranium ornamented with stellate tubercles. Onondaga limestone; Cement Quarry, Buffalo, N. Y. Collected by W. L. Bryant.

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[9] Eastman, C. R. On the characters of *Macropetalichthys*. *Am. Naturalist*, xxxi, 493–499, 1897.
[10] *Mem. N. Y. Acad. Sciences*, x, 100. 1908.

E 1866 Fragment of a cranium with stellate tubercles and showing a sensory canal.

Other data same as preceding.

E 1870 Uncrushed cranium, in inner view. This specimen shows considerable arching of the cranium; greatest width (across marginals) 16.5 cm., greatest depth 5 cm. The head of Macropetalichthys was, therefore, nearly one-third as deep as wide.

Onondaga limestone; Leroy, N. Y. Collected by F. Mixer.

E 1871 Large cranium, in top view, denuded of ornamentation; in counterpart.

Onondaga limestone; Marblehead, Ottawa County, Ohio.

III. ARTHRODIRA

Coccosteus decipiens Agassiz

E 2372 Portions of two individuals showing various head and body plates, the so-called pelvic basipterygia, and the dorsal fin-supports.

Middle Old Red Sandstone; Sandwick, near Stromness, Orkneys.

Coccosteus canadensis Woodward

(Pl. 5, figs. 1–3)

This is the best known of the five or six American species of *Coccosteus*, an almost complete specimen having been described within the past few years by Hussakof.[11] The species is rather rare only one or two plates usually being found in the course of several weeks collecting at the type locality. It is a great satisfaction to the authors to be able to describe a noteworthy specimen, collected by Mr. Bryant in August, 1915. This specimen displays the upper dentition, which is shown for the first time so clearly in a specimen of *Coccosteus*.

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[11] Notes on Devonic fishes from Scaumenac Bay, Quebec. *N. Y. State Mus., Bull.* No. 158, 127–139, pls. 1–3 and 6 figs., 1912.

E 2374 The specimen is contained in a piece of shale, 15 by 21 cm., which had broken out of its place and was picked up at the foot of the bank. It must have been weathered out by ice or frost. The specimen represents a large individual, larger than the one figured by Hussakof, and displays the following plates:

Left Suborbital (*SO*).—This plate is shown in inner view. The anterior process is well developed; its superior surface is broad and excavated for lodging the eye. The whole plate closely resembles that of *Dinichthys*. The upper margin is somewhat broken, but judging from one point at which the entire width of the element is preserved, it would seem that the blade (or plate minus the process), was deeper, i.e., broader, than in other species of *Coccosteus*.

Length, including process, 81 mm.; max. depth (measured at hinder fourth of plate), about 40.

Left Mandible (*Mnd*).—This is represented by the impression of the outer face of a mandible lacking the front half of the functional portion and the posterior extremity of the blade portion. The depth of the blade at its middle is 25 mm. The mandible was therefore of considerable size for a *Coccosteus*; but this is in keeping with the large size of the specimen as a whole. The functional margin of the mandible was a continuous bevelled edge, with denticles (three in number) only at the posterior extremity where it descends to join the blade portion. It was thus strikingly like that of *Dinichthys*. To anticipate the criticism that the specimen is in fact a *Dinichthys* and not a *Coccosteus*, we may say that we have observed a similar condition in *Coccosteus* mandibles belonging to old individuals; one in the British Museum, which is free of all matrix, and which unquestionably is *Coccosteus* coming from the Old Red Sandstone, also shows a bevelled, non-denticled cutting margin; the "teeth" apparently wore off with age, persisting only at the posterior angle where they are not so much exposed to wear.

Left Antero-superognathal (*ASG*).—This element is shown in inner view, and exhibits the area against which the mandibular beak closed. This area is striated by lines of wear. The form of the element is well shown in Plate 5, figure 3. It will be seen that it is rather broad, and that its parts are less differentiated than in *Dinichthys*; hence that it is more primitive than the element in the latter genus. The process for attachment is, however, well developed.

Measurements	mm.
Height (including process and allowing 1 mm. for the missing tip)	25
Greatest width	18
Height of worn area	9
Width of process	7

Left Postero-superognathal (*PSG*).—This, like the preceding element, is shown in inner view (Pl. 5, fig. 2). It resembles the same element in *Dinichthys*. The functional margin shows prettily the lines of wear produced in grinding against the mandibular cutting edge. These lines, it may be mentioned, are, both in this element and in the antero-superognathal, all vertical and parallel to one another, thus proving that the movement of the upper "teeth" against the lower was vertical, with little or no lateral motion. It is noteworthy that the cutting margin is not uniform in width throughout, but that the anterior half is nearly twice as high as the hinder half, there being an abrupt change from the one to the other. (Pl. 5, fig. 2). But whether this feature was pathologic in this specimen, or a constant feature of the species cannot be said. At the posterior end of the cutting margin are two well-developed denticles.

Measurements	mm.
Length, antero-posteriorly	27
Total height (end of process lacking)	22
Maximum height, exclusive of process	19
Height of wearing margin in anterior half of "tooth"	5
Height of wearing margin in posterior half of "tooth"	3

Left Antero-ventrolateral (*AVL*).—This plate is incomplete, only the anterior two-thirds being preserved; it is shown in outer view. As far as preserved it agrees in form with that of the almost complete *Coccosteus* in the

New York State Museum referred to above. It shows the ornamental tubercles well. They are pointed, and stellate at their bases; in the center of the plate they are crowded and very small, while near the periphery they are much larger, fewer, and more widely spaced. A lateral line is present on this plate, as in some other examples of this element in various species of *Coccosteus*. It begins near the inner side at about one-third the length of the element from the front margin, extends inward as a straight shallow groove to about the middle of the plate, then turns upward in a curve; this latter portion being indicated in this specimen only by a double arrangement of the ornamentel tubercles and not by a groove.

Length, as far as preserved, 75 mm.

Width, at level of horizontal arm of lateral line, 61.

Lateral (*L*).—Only the lower limb of one lateral plate is preserved. It is shown in inner view.

There are also the extremities of two other plates preserved, near the edge of the specimen; shown in inner view.

Upper Devonic; Scaumenac Bay, near village of Migouasha, Quebec, Canada. Collected by W. L. Bryant, August, 1915.

Coccosteus parvulus, n. sp.

(Pl. 4, figs. 1–3. Pl. 70, fig. 1)

E 2371 *Cotypes*.—(1) Impression in shale of three cranial plates—a median occipital, shown in inner view, and, on either side of it, a plate shown in outer view (Pl. 4, figs. 1, 3).

E 2372 (2) Impression of outer face of a postero-ventromedian (Pl. 4, fig. 2).

Formation and Locality.—Rhinestreet shale (Portage); Lower fork of Eighteen Mile Creek, near Hamburg, Erie County, N. Y. Collected by W. L. Bryant.

A species of about the size of *Coccosteus decipiens*, with plates ornamented with small, closely-crowded, stellate tubercles. Distinguished from other species by the form of the plates mentioned above. Postero-ventromedian lozenge-shaped, with broad lateral flanges for overlap by the other ventral plates; length, 15 mm., width, 11. Some of the tubercles of this plate, as seen in a wax squeeze, are clearly stellate. Median occipital distinguished from that of other species by the fact that its lateral margins do not converge rapidly anteriorly; i.e., the plate, exclusive of the postero-lateral cornua, is more nearly rectangular than in other species, for example in *C. decipiens*, in which it is triangular with the apex of the triangle cut off.

Remarks.—This is one of the smallest American species of *Coccosteus* known. It recalls *C. macromus* Cope, from the Chemung, but this species was based on one or two plates almost too fragmentary for identification as *Coccosteus*.

The following specimen apparently also belongs to this species.

E 2597 Impression of a cranial shield, of which nearly the entire outline can be made out (Pl. 70, fig. 1). A few of the sensory canals are also discernible. From the strong posterior excavation of the median occipital, which resembles that of the cotype (Pl. 4, fig. 3); from its size, and geological horizon, it apparently belongs to this species. The head is rather more elongated anteroposteriorly than is usual in *Coccosteus*.

Measurements	mm.
Total length	82
Length, tip of rostrum to middle of posterior margin of med. occipital	70
Width at middle of orbits	40
Greatest width, posteriorly	80

Coccosteus, sp.

In addition to the preceding specimens there are a number of more or less fragmentary coccosteid remains in the Buffalo museum. Those from the Rhinestreet shale, listed below, perhaps belong to *C. parvulus*, but there is no proof of this at the present time.

a. Specimens from the Conodont bed, at Eighteen Mile Creek, near North Evans, N. Y.; collected by W. L. Bryant.

E 2375 A very small antero-dorsolateral, imbedded in matrix, representing a species about the size of *Coccosteus parvulus*. The width of the element is 13 mm.; its length at the process, 6.5. It shows the areas for overlap by the dorsomedian and lateral plates. A lateral line is present; it extends from the articulating process, is somewhat curved, and is especially well-shown on the posterior half of the element.

We refer this specimen provisionally to *Coccosteus*, but it may represent an immature individual of some other Arthrodire.

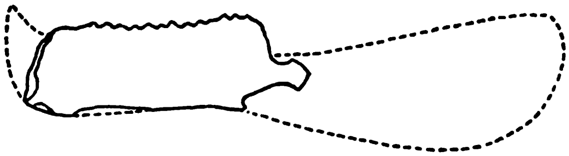

FIG. 4. *Coccosteus* sp. ANTERIOR HALF OF A MANDIBLE, NATURAL SIZE
Its restored outline is indicated by the broken line. E 2378.

E 2376 A postero-ventromedian, in matrix, shown in outer view (Pl. 4, fig. 5). It is ornamented with very small, pointed stellate tubercles, which are largest near the centre of the plate and gradually decrease in size and finally disappear toward the margins. Length in antero-posterior diameter, 40 mm.; greatest width, 30.

E 2377 A postero-ventromedian, on a piece of matrix, shown in inner view (Pl. 4, fig. 4). The outer face, as appears from an impression of a corner of the plate, is ornamented with fine tubercles.

b. Specimens from the Rhinestreet shale (Portage); Eighteen Mile Creek, N. Y.

E 2378 Functional portion of a small mandible lacking the "beak" (fig. 4). The entire functional margin is preserved; it shows a row of teeth extending over its entire length, except at the anterior extremity. The teeth are worn and not well-preserved. The margin back of the functional area drops abruptly down to meet the blade portion. Length of cutting edge, as far as preserved, 28 mm.; depth of blade, 11. About 13 teeth can be counted. It is probable that this mandible belongs to our *Coccosteus parvulus*.

E 2505 A thin plate traversed by a branched lateral line, represented by the impression of its outer, ornamented face. The ornamentation is finer than in the type specimens of *Coccosteus parvulus*, and the plate perhaps belongs to a different species. Collected by W. L. Bryant.

Dinichthys terrelli Newberry

(Pl. 6, figs. 1–3)

This, the type species of the genus, is represented in the collection by a mandible and a plate, found separately. They are from the type locality, the Cleveland shale (Upper Devonic), at Linndale, near Cleveland, Ohio; and, like all the other specimens from this formation described in the catalog, were collected by Mr. Bryant, in August, 1914.

E 2379 A fine left mandible, in splendid preservation (Pl. 6, figs. 2, 3). A photograph of this specimen was compared with a very fine left mandible in the American Museum (No. 15 Newb. Coll.) which was figured by Newberry[12] himself as representing this species; and it agrees well with it in size and general form. The beak is pointed, and there are three vestigeal denticles at the posterior end of the cutting blade, of which the most anterior one is the largest.

Measurements	*cm.*
Total length	48.5
Length of functional portion	24.0
Height at tooth	16.0
Height at posterior end	22.0

E 2380 Impression of a very large right suborbital (Pl. 6, fig. 1). When found the bone itself was present, but this was badly shaken up, and partly lost in transportation, so that on

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[12] *Rept. Geol. Surv. Ohio, Palæont.*, pl. ii, chart 5, fig. 6, 1875.

reaching the laboratory it was completely removed and a cast taken of the impression in the rock. A photograph of this specimen was compared with two suborbitals in the American Museum (Nos. 7298 and 7306 Newb. Coll.), which were figured by Newberry as of *Dinichthys terrelli.*[1] It agrees with these except that it is even larger.

Measurements	*cm.*
Total length (including process)	57.0
Length of body of plate	41.0
Greatest height of body of plate	27.5

Dinchthys intermedius ? Newberry

E 2499 Impression of an antero-ventromedian (fig. 5); probably referable to this species.

Cleveland shale; Linndale, near Cleveland, Ohio. Collected by W. L. Bryant, 1914.

Median ventral plates of *Dinichthys* are rather rare. Of those belonging to the Ohio species there are probably not more than a dozen all told in collections, notwithstanding that collecting has been going on for nearly half a century.

As seen from the figure, the present plate is bilaterally symmetrical, tapers to a point, and was without question distinct from the postero-ventromedian. It is known that in some species of *Dinichthys*, e.g., in *terrelli*, the antero- and the postero-ventromedians were fused into a single elongated plate, whereas in other species, for instance, in *intermedius*, the antero- and the postero-ventromedians were separate plates, the antero-ventromedian narrowing posteriorly, and its extremity fitting into a socket on the outer face of the front end of the postero-ventromedian. The present specimen clearly belongs to the type which has the antero- and postero-ventromedians distinct; and from its size it would appear to belong to *Dinichthys intermedius.* We have compared it with three more or less perfect examples of this plate in the American Museum collections. There is a good deal of variation among these plates, and the present specimen differs somewhat from all with which it has been compared, although in its general form and proportions it agrees pretty well with one of these specimens, also supposed to belong to *Dinichthys intermedius.*

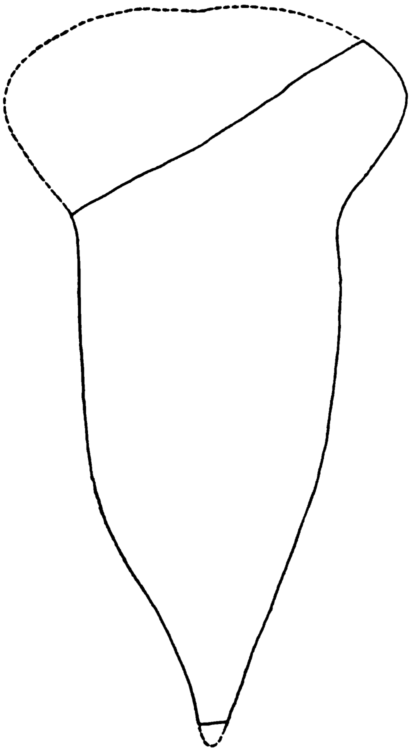

FIG. 5. *Dinichthys intermedius ?* Newberry. OUTLINE OF THE IMPRESSION OF AN ANTERO-VENTROMEDIAN. × ½. E 2499

Dinichthys intermedius ? Newberry

E 2033 A pair of rather small mandibles (fig. 6), associated with several fragmentary *Dinichthys* plates, in outer view, on a slab of shale. The mandibles measures 17.5 cm. in length, and 6 cm. in height (at the beak); and the beak of the right mandible overlaps that of the left. The cutting margins are not well preserved, but can be made out for their entire length; there are no denticles preserved on the posterior portion of the functional margin.

Rhinestreet shale (Portage); shore of Lake Erie at Sturgeon Point, Erie County, N. Y. Collected by F. K. Mixer.

At a first glance these mandibles look rather peculiar, and Eastman (*Bull. Museum Compar. Zoöl.*, xxxi, 31) thought that "their affinities are probably with *Dinichthys minor*." This was before the mandible of the latter had been described. But as was shown by Hussakof,[13] the *minor* mandible is markedly different from that of *Dinichthys*, so much in fact, that it represents a distinct genus, which he named *Brachygnathus* (subsequently renamed *Hussakofia* by M. Cossman).[14] The present mandibles are not of this type but undoubtedly belong to *Dinichthys*.

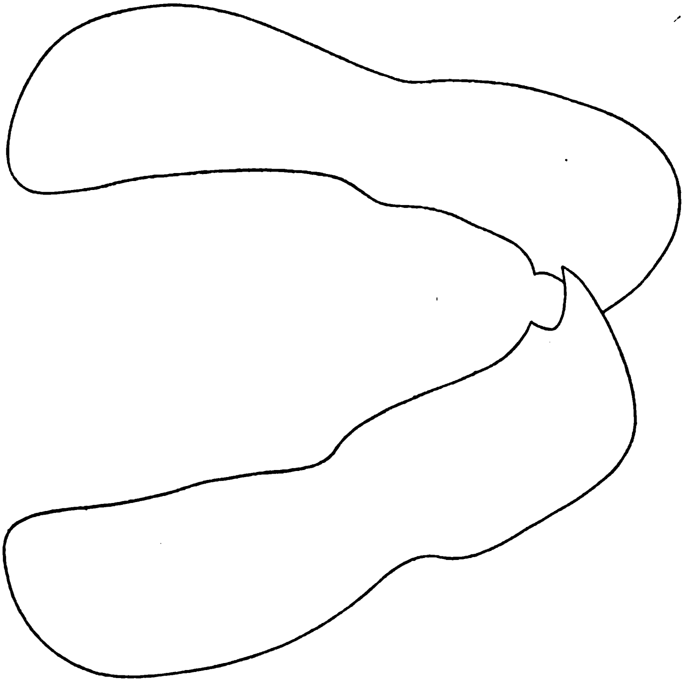

FIG. 6. *Dinichthys intermedius ?* Newberry. PAIR OF MANDIBLES. × ½.
E 2033

If we compare the mandibles in detail with those of various species of *Dinichthys*, we find that they agree fairly well in proportions with those of *D. intermedius* Newberry, and perhaps represent an immature

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[13] Hussakof, L.: The systematic relationships of certain American Arthrodires. *Bull. Am. Mus. Nat. Hist.*, xxvi, 263–272, with pl. xlv. 1909.
[14] Cossman, M., in *Rev. Critique de Paleo*, 1910, p. 74.

specimen of this species. Their unusual appearance is due to their little wear by use, the beak still retaining its juvenile pointed condition, and the excavation back of it, produced by the upper "tooth," being still but little worn down.

If we compare the mandibles with the figures of those of *Dinichthys intermedius* given by Newberry (*Paleoz. Fishes of N. A.*, 1889, Pl. x), we find them closely similar to the latter. Thus, the functional part is somewhat shorter than the blade portion; the depth of the functional portion, at its middle, is contained 1⅓ times in the depth of the blade portion, at its middle; and the depth at the junction of the blade and functional portions (measured from the upper point of junction) is contained 2⅓ times in the length of the blade portion. These proportions correspond so closely with those of the mandible of *Dinichthys intermedius*, as to lead us to believe that the present specimens probably belong to this species.

Dinichthys magnificus, n. sp.

(Pls. 1, 7, 8, 9; Pl. 17, fig. 3; Pl. 22, fig. 1; text-figs. 7, 8, 9, 11, 12)

The most impressive and perhaps most valuable specimen of the entire collection in the Buffalo museum, is a magnificent head and body armor of a large species of *Dinichthys*. It was found in a huge concretion (fig. 7) derived from near the base of the Rhinestreet shale. A portion of the concretion was discovered by Mr. Frederick Houghton, of the Buffalo museum, and the remainder, which had drifted out of place, was found the following year by Mr. Bryant. The specimen exhibits the head and most of the body plates of a huge *Dinichthys*. Several of the plates were extricated from the matrix, others were carefully copied in plaster, or squeezes were made of those represented by impressions, and the whole has been set up in a restoration which makes a splendid exhibition specimen (Pl. 1). It is clear that the species is different from any other known, and we therefore describe it here as new.

E 2381 *Type.*—Head and body armor of a large *Dinichthys*, in a concretion. The plates present are shown in figure 8, in which the specimen is represented as if laid out flat. The parts preserved are the head shield; a complete sclerotic ring, composed of four segments, a fragment of the right suborbital; the larger part of the left mandible; an imperfect antero-superognathal; impression of a postero-superognathal; larger portion of the dorsomedian; an anterior, and both posterior ventrolaterals; the postero-ventromedian; a spine-like element, and portions of a lateral or "clavicular" plate.

Formation and Locality.—Basal concretionary portion of the Rhinestreet shale (Portage); Eighteen Mile Creek, near Hamburg, Erie County, N. Y. Collected by W. L. Bryant and Frederick Houghton.

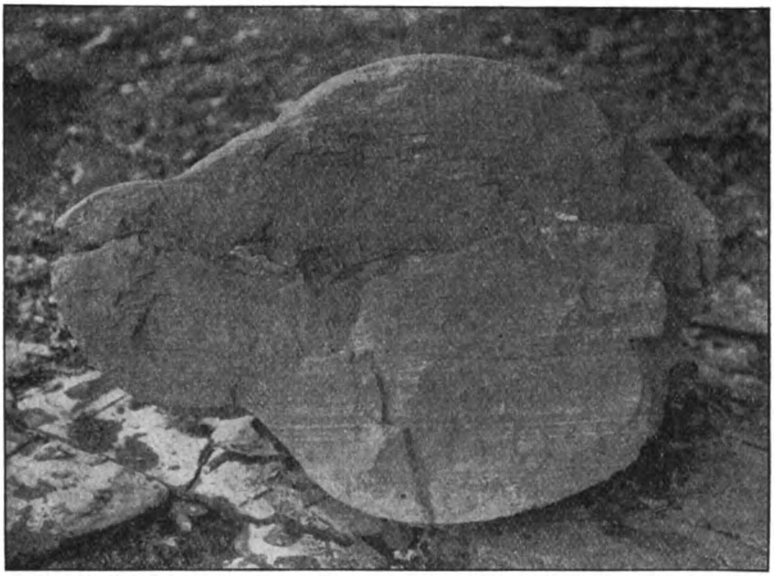

FIG. 7. CONCRETION CONTAINING THE TYPE OF *Dinichthys magnificus*, AS FOUND
Near base of Rhinestreet shale (Portage); Eighteen Mile Creek, near Hamburg, N. Y.

A species as large as *Dinichthys terrelli*, ornamented with very small, and mostly closely-crowded, non-stellate tubercles; distinguished especially by the forms of the head and the mandible. Head narrower anteriorly than in any other species; its outline, when viewed from above, sub-triangular; preorbital margin rounded; median occipital short but very broad, and tripartite along its anterior margin. Lateral lines traversing the preorbital gently curved outward at their anterior extremities and not reflexed into curves concave toward the

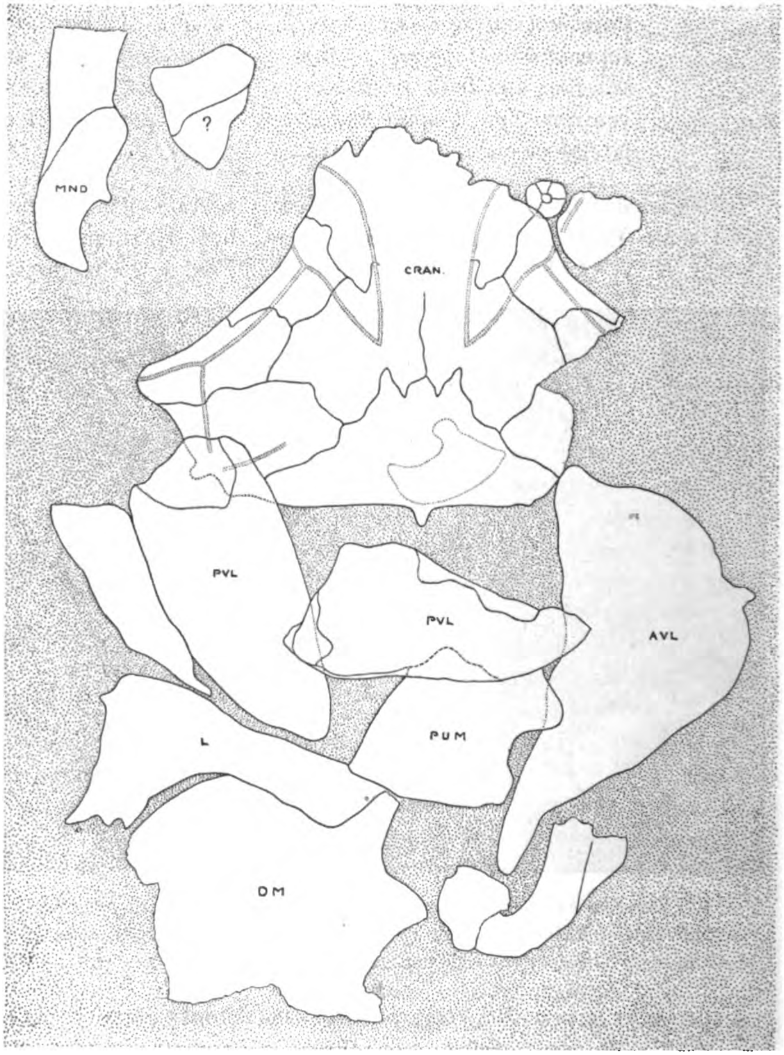

FIG. 8. *Dinichthys magnificus*, n. sp. OUTLINE OF PLATES SHOWN IN THE TYPE SPECIMEN. × ⅓. E 2381

AVL, antero-ventrolateral; *CRAN*, cranium. (Near right orbit is the complete sclerotic ring of that side). *DM*, dorsomedian; *L*, one arm of lateral, or "clavicular;" *MND*, mandible; *PVL*, postero-ventrolateral; both plates are preserved. *PVM*, postero-ventromedian.

median line. Eye surrounded by a sclerotic ring composed of four segments. Mandible of the usual *Dinichthys* type; distinguished by the great distance between the beak and the secondary cusp, the latter being situated toward the middle of the cutting margin.

Remarks.—This species is one of the largest dinichthyids known. It can be compared in size only with *Dinichthys terrelli* of the Cleveland shale of Ohio, from which, however, it is strongly differentiated. It proves that the Ohio dinichthyids were not the only large Arthrodires that existed in late Devonic times, but that coevally with them there lived in the Portage sea of New York, a *Dinichthys* equally huge and powerful.

The following is a detailed account of the plates displayed by the type specimen:

Cranial shield (fig. 9).—The head is fairly well-perserved, most of the bone being present, and the sutures and lateral lines can be clearly made out. The only parts missing are the rostral and a portion of the right side. Owing to the favorable conditions of its fossilization, in a concretion, the head is but little crushed down, and shows considerable arching from side to side.

Its most noteworthy feature is its narrowness anteriorly (compare figs. 9 and 10), so that when viewed from above it appears much more triangular than the cranial shield of *D. terrelli*, or in fact that of any other species known.

The median occipital element is very short antero-posteriorly, but extremely broad, being greatly extended laterally at each side; anteriorly it is divided into three short lobes, a median one and a somewhat narrower one on either side of it.

Another peculiarity of the head shield is to be found in the direction of the preorbital canals. In all species of *Dinichthys* thus far known, these canals have near their anterior extremities, in the region of the rostral element, a secondary curve, concave toward the median line. In the present species there are no such secondary curves, but instead, the anterior moieties of these canals curve outward toward the antero-lateral angles of the head and terminate at the rounded angles anterior to the orbits.

Measurements	*cm.*
Length in median line, with allowance for missing rostral	55
Width across posterior angles of orbits[15]	32
Width across angles of marginals[15]	70

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[15] Based on the half preserved.

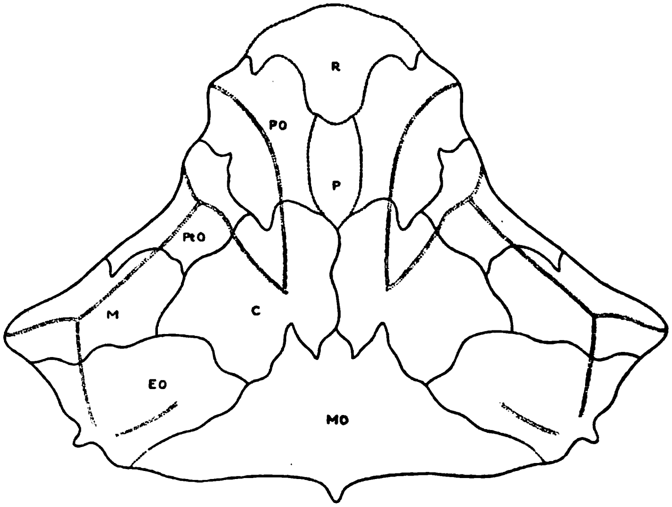

FIG. 9. *Dinichthys magnificus*, n. sp. OUTLINE OF CRANIUM OF TYPE SPECIMEN

The rostral and pineal elements are restored, the former being based on the specimen shown in Plate 17, figure 1. *C*, central; *EO*, external occipital; *M*, marginal; *MO*, median occipital; *P*, pineal; *PO*, preorbital, *PtO*, postorbital; *R*, rostral. × ⅛.

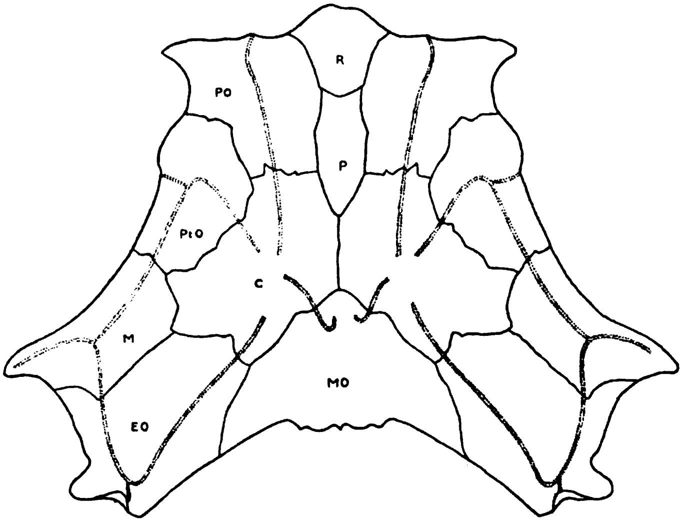

FIG. 10. *Dinichthys terrelli* Newberry. OUTLINE OF CRANIUM FOR COMPARISON WITH THAT OF *D. magnificus*

Lettering same as in figure above. × ⅛. (After Hussakof.)

Sclerotic ring (fig. 11).—A feature of great interest in this specimen is the preservation of a complete sclerotic ring, situated near the right orbit, and not far removed from its natural position. It is of great importance as affording for the first time a correct idea of the form of the eye in *Dinichthys*.

Complete sclerotic rings of Arthrodira are extremely rare, owing to the fact that on dissolution of the animal the segments composing the ring became more or less disarranged and usually drifted apart. The most perfect example of an arthrodiran sclerotic ring hitherto known is the one belonging to the type specimen of *Trachosteus*, which was figured by Newberry (*Paleoz. Fishes N. Amer.*, Pl. xlii, fig. 2). It consists of four segments of very thin bone united by wavy sutures so as to form a ring.

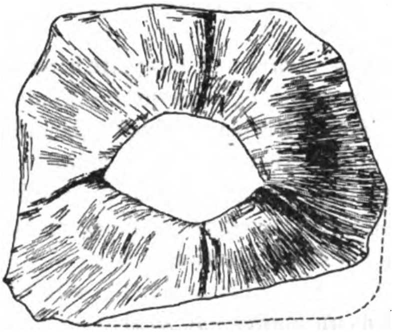

FIG. 11. *Dinichthys magnificus*, n. sp. SCLEROTIC RING, NATURAL SIZE. LOWER MARGIN RESTORED

In the present instance the sclerotic ring is not flattened down but preserves much of its original outward convexity, this convexity representing the configuration of the eyeball, which we thus learn was spherical as in other vertebrates. The ring is composed of four segments; and the opening in the centre, corresponding to the eye proper, is not round but ovate, with the narrow ends drawn out to points. Its form is thus proved to have been much like that of sharks and many other fishes.

The sclerotic ring measures 50 mm. in width, and 11 mm. in height. The eye opening is 20 mm. in long diameter (measured at the lateral angles), and 15 in greatest width.

Mandible.—Only the left mandible is preserved, and this lacks the hinder third. Its form is well shown in the photograph reproduced in

Plate 7, fig. 1, so that no lengthy description of it is necessary. Its outstanding features are the low, broad beak, and the position of the secondary cusp, which is situated far back, near the middle of the functional margin. It is this feature which has enabled us to identify as of this species one or two upper shear teeth, since the groove worn in the sheer plate by the secondary mandibular cusp must be situated farther back in this species than in others.

Antero-superognathal.—The left element is represented; it is badly fractured, the median lateral flange being broken away. The main cusp and the articulating process are however present.

Postero-superognathal.—The left postero-superognathal lay beneath the median occipital, and a complete cast of it was obtained. It is shown in the restoration, Plate 1. There are no posterior denticles and the inner face exhibits a deep groove worn by the posterior mandibular cusp.

Dorsomedian.—Only a portion of this plate is preserved. A cast reconstructed from it measures 15 inches in length, and 17 inches in greatest width. The surface of the plate is finely tuberculated, the tubercles being, if anything, smaller than those of *D. pustulosus*. It is also noteworthy that the plate is strongly arched from side to side, and, like the head shield, apparently suffered little deformation, owing to its favorable preservation in a concretion.

Lateral or "Clavicular."—This element was represented in the opened concretion as an impression, so that a cast could be taken of almost the entire plate. Its form and proportions are clearly indicated in Plate 7, figure 2. The posterior margin measures 25.4 cm. in length, and the inwardly directed arm, 12.6 cm. The outer surface is partially tuberculated.

Ventral Armor.—Of the ventral armor there are preserved the postero-ventromedian, an antero-ventrolateral and both postero-ventrolaterals.

The *postero-ventromedian* (Pl. 22, fig. 1) is shown in the specimen in inner, or visceral view. It is 25.4 cm. in length, and 20.3 cm. in greatest width. It is much wider in proportion to its length than its homolog in *D. terrelli*, and as the anterior end is missing, it cannot be stated whether it was fused with the anterior element into a single ventromedian, as in *D. terrelli*, or was united with it by a socket joint as in most other species.

The *antero-ventrolateral* preserved is that of the left side, shown in inner or visceral view. Its inner margin is broken away. The plate is arched from side to side, which indicates a more natural condition than usual since ventral plates are very thin and generally found flattened out. A thickened process occurs on the anterior edge which is, apparently, a device for interlocking with the antero-median-ventral. Length of plate, 50.8 cm.; anterior border, about 35 cm.

Both *postero-ventrolaterals* (Pl. 7, fig. 3) are preserved. They are exhibited in outer view and show near the anterior margins, the depressions into which the distal extremities of the corresponding antero-ventrolaterals fitted. The right postero-ventrolateral lacks the front border, but as far as preserved it measures 38 cm. in length, by 17.5 cm. in greatest width. Along the inner margin is an elongated, irregular depression into which the plate of the opposite side fitted, in the manner demonstrated for *Dinichthys* by A. A. Wright.[16] The surface of the plates is finely tuberculated, and along the inner margin the tubercles have a tendency to a linear arrangement.

A knife-shaped spiniferous plate similar to that shown in Plate 17, figure 3, was found overlying the cranium in the orbital region. One end is thickened, the other is formed into a sharp blade.

In addition to the preceding plates there are fragments of two or three others, too imperfect for description. One is a fragment of a suborbital, lying to the right of the cranium and showing a small part of the lateral line that traverses this plate. Another is a fragment of an antero-dorsolateral, showing the articulating process.

Besides the type specimen there are several plates in the collection which seem referable to this species. They are all from the Conodont bed (Genesee), at Eighteen Mile Creek, near North Evans, N. Y., and were collected by W. L. Bryant.

E 1936 Functional half of a left mandible represented in outer view in Plate 8, figs. 1, 1a, and in inner view, in text-figure 12.

We refer this specimen to *D. magnificus* for the reason that the beak is rather low for a mandible of this size, and the secondary cusp is situated at a considerable distance from it—the two features by which the mandible of this species is especially distinguished. An important character in this specimen is the presence of a row of teeth in the symphyseal region. Only the two lowermost ones

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[16] Wright, Albert A.: The ventral armor of *Dinichthys*. *Amer. Geologist*, xiv, 313–320, pl. ix, 1894.

are clearly shown (fig. 12, *s*), the others being weathered away. The lowermost one has a diameter of 3.5 mm., and is situated about midway between the tip of the beak and the basal margin.

Measurements	*cm.*
Height at beak (lower margin slightly restored)	8
Length, as far as preserved	11
Depth of functional portion (slightly restored)	6

E 1960 Posterior blade of a right mandible, a part of it represented only by the impression (Pl. 8, fig. 2).

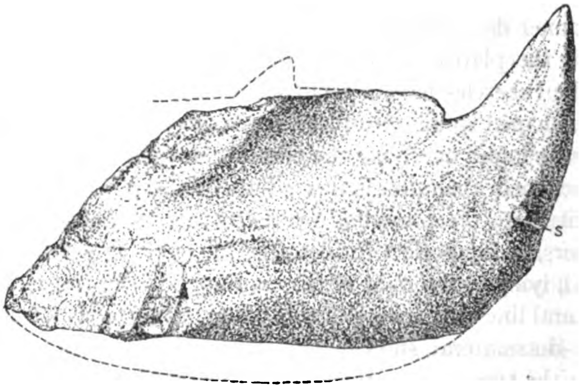

FIG. 12. *Dinichthys magnificus*, n. sp. ANTERIOR EXTREMITY OF A LEFT MANDIBLE, IN INNER VIEW. SYMPHYSEAL DENTICLE. × ⅛. E 1936

This specimen differs somewhat from the blade portion of other dinichthyid mandibles, and perhaps belongs to this species. It is of about the size to go with the functional portion of a mandible described above (E 1936). It is interesting to note that near the lower margin of the blade is a scar apparently inflicted by the teeth of another animal, the plate having been completely bitten through.

E 1937 An imperfect large left postero-superognathal (Pl. 9, fig. 3). The area worn by the secondary mandibular cusp is situated farther back than is usual, thus indicating that the second cusp of the mandible was relatively far back;

and this points to the specimen belonging to *D. magnificus*. Only the proximal portion of the articulating process is preserved.

E 1942 A rather small left postero-superognathal, perfect except for the absence of the articulating process (Pl. 9, figs. 1, 2) Length, 89 mm.; maximum width, 41.

This specimen was found unassociated with other plates. Our reason for referring it to this species is the same as that for the preceding specimens, namely, the fact that the worn edge shows that the secondary cusp of the opposing mandible was situated far back, as in *D. magnificus*. The element resembles E 1937 as far as the preservation of the latter allows of comparison, but it is only about two-thirds its size.

Dinichthys newberryi Clarke

(Pls. 10, 11; text-figs. 13, 14)

This species was originally based[17] on a right mandible, a postero-superognathal and fragmentary cranial plates, all contained in a concretion from the *Styliola* layer of the Genesee, at Bristol Center, N. Y. A dorsomedian plate found at another locality, but in the same horizon, was also referred to by Clarke as probably belonging to this species.

The type, which is preserved in the United States National Museum, was kindly lent us recently for comparison with the material in the Buffalo museum. Since it has never been figured in its entirety, only the mandible having been illustrated by Clarke, and subsequently by Eastman,[18] we deem it desirable to present an outline figure of it here (fig. 13). From this it is seen that there are present in the type specimen the right mandible (*Mnd*), the left postero-superognathal (*PSG*), a section, apparently of one of the antero-superognathals (*ASG*), a segment of a sclerotic ring (*Scl*) and an indeterminate plate (*X*). It is important to note also that a fragmentary plate displayed on the under side of the same concretion, proves that the plates of this species are not, as stated by Eastman,[19] smooth and unornamented,

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[17] Clarke, John M.: *Bull. 16, U. S. Geol. Surv.*, 1885, p. 17, pl. i, fig. 1.
[18] *Mem. 10, N. Y. State Mus.*, 1908, pl. 6, fig. 2.
[19] Loc. cit. p. 133.

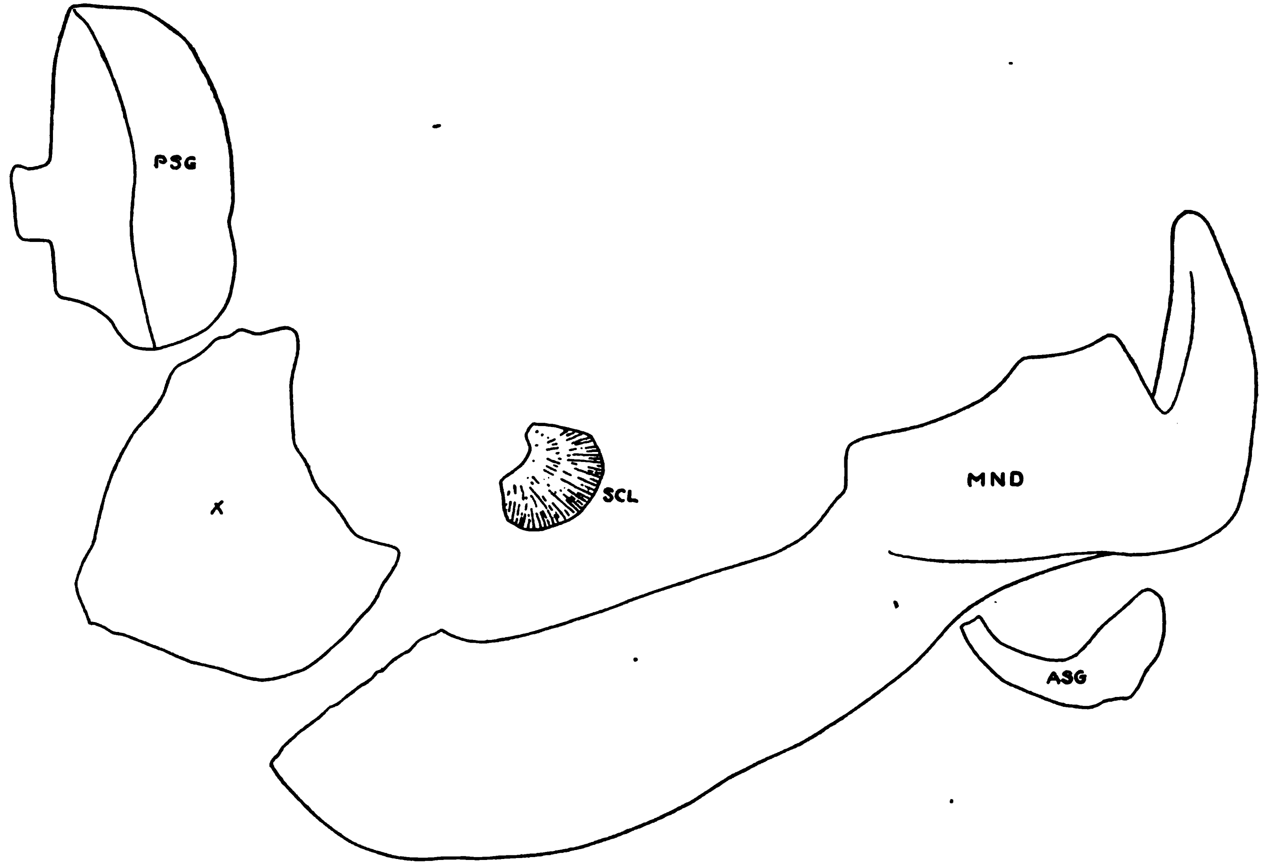

FIG. 13. *Dinichthys newberryi* Clarke. OUTLINE OF PLATES SHOWN IN THE TYPE SPECIMEN. × ½

ASG, section through an antero-superognathal; *MND*, right mandible, in outer view; *PSG*, left postero-superognathal, in outer view; *SCL*, segment of sclerotic ring; *X*, indeterminate plate. Specimen is in the U. S. Natl. Mus.

Styliola layer (Genesee); Bristol Center, N. Y.

but bear an ornamentation of fine stellate tubercles very similar to those of *Dinichthys pustulosus.*

We may now record that *Dinichthys newberryi* occurs in the Conodont bed, at Eighteen Mile Creek, where it is found associated with the remains of four or five other species of *Dinichthys.* The remains represented in the Buffalo museum consist of mandibles, upper dental plates, and various more or less fragmentary elements of the head and body armor.

As to the species in which these mandibles belong, there can be no doubt, since they show the elongated beak characteristic of this species.

FIG. 14. *Dinichthys newberryi* Clarke. MOUNTED RESTORATION OF THE DENTITION. × ⅛

The antero-superognathals, or front upper teeth, range from very small specimens only 31 mm. in height, to large ones equalling those of *D. intermedius,* and which probably represent full-grown individuals. Our reference of these elements to *Dinichthys newberryi* is based on the fact that the worn area on the inner face is unusually long and narrow, thus proving it to have been caused by an elongated mandibular beak of the kind present only in *D. newberryi.*

The ventral plates and the antero-dorsolateral described below, are only doubtfully referred to this species. Our main reason for so referring them is that they bear an ornamentation of fine tubercles somewhat like those seen on the fragmentary plate belonging to the type specimen of *D. newberryi.*

The following specimens are referred—some positively, others only tentatively—to this species. All are from the Conodont bed (Genesee), at Eighteen Mile Creek, Erie County, N. Y., and were collected by W. L. Bryant.

E 2382 Functional half of a left mandible lacking the inferior margin; in matrix, shown in outer view (Pl. 10, fig. 2). The beak is elongated, and back of it there is a smooth, untoothed cutting edge. The front portion of this cutting edge has lost its beveled margin, while the posterior half has not; this produces the illusory appearance of a cusp situated far back on the cutting margin. The full length of the cutting margin is preserved, the break occurring at the beginning of the blade portion. The specimen seems to have been about the size of the type mandible, and as far as preserved agrees with it in character (cf. fig. 13). We think there is no doubt that it is referable to *Dinichthys newberryi*.

Measurements	mm.
Total width of functional region, including beak.....	116
Height of beak (measured on a perpendicular).......	40
Width of beak at its base.........................	33
Length of cutting margin (exclusive of beak)........	83

E 1939 A left antero-superognathal (Pl. 11, figs. 1, 1a, and text-fig. 15) of about the size to go with the mandible described in the preceding paragraph. This and the following examples of upper dental plates almost positively belong to this species. The element is easily distinguished from other antero-superognathals; first, by the broader and much thinner articulating process, which is very different from the thick process, broadly elliptical in cross-section, seen in *D. terrelli* and related forms; second, by the median lateral portion of the tooth (the opposite side to that of the process) not being so much in-rolled as in the Ohio species.

Measurements	mm.
Total height (point of tooth restored)................	93
Total width...	65
Width of process....................................	31
Length of tooth portion (estimated)	45

E 1940 A left antero-superognathal (Pl. 10, figs. 1, 1a), somewhat smaller than the preceding, and defective on the median part of outer face; it also lacks the tip of the tooth and the distal half of the lateral wing. The articulating process is correspondingly smaller than in the preceding specimen. Height, 86 mm.

E 1955 A juvenile left antero-superognathal, smaller than the preceding (Pl. 11, figs. 2, 2a). It lacks the lateral wing. The tooth portion is long in comparison with the process, a fact also observed in the juvenile antero-superognathals of other species. From the character of the process and the general appearance of the element, it unquestionably belongs to the same species as the preceding three. Height, 31 mm.; greatest width, 17; width of process, 9.

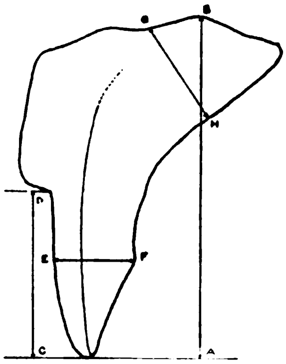

Fig. 15. Diagram Showing how Antero-Superognathals Described in this Catalog were Measured

A—B, total height; *C—D*, tooth portion of element; *E—F*, width of tooth; *G—H*, width of process. The total width (not indicated by letters), is the extreme width measured along the line, *AC*.

E 1956 A juvenile left antero-superognathal, about one-third the size of the preceding, lacking the tooth and the greater portion of the lateral wing. It agrees closely in general form with the preceding two elements. The process is broad and quite flat. Total height (estimated), 37 mm.; width of process, 14. (Pl. 27, fig. 2.)

E 2383 A left antero-superognathal, lacking the inner flange; in matrix, shown in outer view. Height, 76 mm.

E 1985 An imperfect right antero-dorsolateral. The plate is of fair size and shows the articulating process. The upper surface is much obscured by a very thin deposit of matrix, but the ornamental denticles may be seen in places, and the lateral line is preserved (though it is much obscured), as well as the excavation on the right for overlap by the lateral plate. Posteriorly the element thins out to a paper edge apparently not far from the natural margin.

Length, antero-posteriorly, without process, 13 cm.; width (allowing for missing left margin), about 20.

It seems to us probable, because of its size and the character of the ornamental denticles, that this plate belongs to *D. newberryi*.

E 1986 Postero-medianventral. This specimen is smaller than that of the Portage specimen (E 2032) illustrated in figure 17; and it was clearly not fused with the antero-ventrolateral. (Pl. 28, fig. 3.)

Dinichthys pustulosus Eastman

(Pl. 12; pl. 13, figs. 1, 2)

This species is represented in the collection by material from three different horizons and localities:

1. A number of plates from the typical formation and locality, the Hamilton limestone of Wisconsin. Some of them display the characteristic ornamentation consisting of small tubercles stellate at their bases. Two of the specimens are plates not previously known in this species—the antero-superognathal and the antero-ventromedian.

The antero-superognathal (Pl. 12, fig. 1), may be regarded as a rather primitive, unspecialized example of this element. The inner face (the one bearing the secondary tooth) is broad, the tooth proper is small, and the articulating process short. The other two elements of the jaw, the mandible and the postero-superognathal, have already been described, so that the entire dentition of *D. pustulosus* is now known.

The antero-ventromedian (Pl. 12, fig. 2) is of the form usual for this element. Its outer face is covered with ornamental denticles. It is undoubtedly a complete plate, and shows that it was articulated, not fused, with the postero-ventromedian.

We figure (Pl. 12, fig. 3) a very perfect example of the right antero-dorsolateral plate of this species. The original, from the Hamilton Limestone of Milwaukee, Wis., is in the private collection of Mr. E. E. Teller, of Buffalo.

2. A number of more or less fragmentary remains from the Conodont bed (Genesee), at Eighteen Mile Creek. These plates are referred to this species with some reservation, since they are all fragmentary and none have been found associated. The principal reason for referring them to this species is the character of their ornamentation; but as a somewhat similar ornamentation occurs in *Dinichthys magnificus*, also found in the Conodont bed, it is quite probable that some of the specimens at least may belong to the latter species. The occurrence of *D. pustulosus* in the Conodont bed is not surprising since the species has been previously recorded[20] from a Genesee horizon, namely the New Albany black shale, near Lexington, Kentucky.

3. Several fragmentary plates from the Genundewa limestone (Genesee), of Eighteen Mile Creek.

a. Specimens from the Hamilton limestone, Milwaukee, Wis. Collected and presented by Mr. Edgar E. Teller.

E 1894 Imperfect dorsomedian showing the keel; one side of the plate is completely preserved. Length in median line, without process, 17.5 cm.; estimated width when complete (measured across widest part) 21.

E 1896 Beak of a right mandible (Pl. 13, fig. 2); it is interesting for showing a vertical row of denticles in the symphyseal region.

E 2384 Cast of a left antero-superognathal in matrix, shown in outer view (Pl. 12, fig. 1). This is the specimen referred to above as the first example of this element in *D. pustulosus* to be made known. Height, including process, 74 mm.; total width, 44. Original in Mr. Teller's private collection.

E 2385 Cast of an antero-ventromedian of a rather small individual (Pl. 12, fig. 2). Length, 10 cm.; maximum width, at

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[20] *N. Y. State Mus. Mem. 10*, 1907, p. 133.

front, 5.5. The specimen is of the usual form for this element, and shows the thinning at the lateral margins for overlap by the antero-ventrolaterals. On the inner face the plate is perfectly smooth and bears a low, rounded ridge along the anterior margin, and, extending backward from this down the middle line of the plate, a longitudinal ridge. The outer face of the plate is ornamented, although scantily, with the characteristic tubercles of this species. Original in private collection of Mr. Teller.

b. Specimens from the Conodont Bed (Genesee); Eighteen Mile Creek, at North Evans, Erie County, N. Y. Collected by W. L. Bryant.

E 1973 Left marginal plate of cranium, showing sensory canals (Pl. 13, fig. 4). The plate agrees in form, size and the character of its tuberculated ornamentation with that of *Dinichthys pustulosus*, and, in the absence of evidence to the contrary may tentatively be placed in this species.

E 1974 Imperfect suborbital, showing sensory canal.

E 1975 Incomplete cranial plate bearing sensory canals.

E 1976 A spiniferous plate. This element is of similar form, though much smaller size, than the one figured by Newberry (*Paleoz. Fishes N. Am.*, 1889, Pl. v, figs. 4–5) in *Dinichthys intermedius*. It is tuberculated on its outer surface, and measures 9.5 cm. in length and 1.5 cm. in width.

E 1977. An incomplete ventral plate.

E 1978 Incomplete plate bearing tuberculated ornamentation.

E 1979 An imperfect plate bearing tuberculated ornamentation.

E 1983 Imperfect median occipital of cranium.

c. Specimens from the Genundewa limestone (Genesee); near mouth of Eighteen Mile Creek, Erie County, N. Y. Collected by Mr. F. K. Mixer.

E 1980 Right postero-lateral margin of a cranium, showing a branching sensory canal. This plate was referred to by Eastman (*Bull. Mus. Compar. Zool.*, 1897, xxxi, 40) as a suborbital, and the specimen was erroneously attributed to the Encrinal limestone.

E 2026 About half of a large ventrolateral plate, 21 cm. in greatest width, and about the same dimension in length, which probably belongs to this species. It bears an ornamentation of stellate tubercules, somewhat variable in size. This plate was briefly described by Eastman (*Bull. Mus. Comp. Zool.*, 1897, xxxi, 40) who regarded it as very probably belonging to *D. pustulosus*. It was originally attributed to the Encrinal limestone, but an examination of the matrix convinces us that it is from the Genundewa limestone (Genesee).

Dinichthys insolitus, n. sp.

(Pl. 27, fig. 3)

E 2387 *Type.*—A small right antero-superognathal; total height, 39 mm.; width at middle of tooth portion, 8; width of process, 18.

Formation and Locality.—Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Antero-superognathal small and slender; articulating process broad, flat, and not thickened. External face without denticles. Inner vertical margin a sharp edge with no trace of a secondary, or inner, cusp. Outer lateral margin with an excavation for receiving proximal end of the postero-superognathal; this excavation occupying about one-half the total height of the element, and beginning nearer tip of tooth than upper end.

Remarks.—This is a well-marked species readily distinguished from all others by the absence of the secondary cusp, and by the remarkable excavation for interlocking with the postero-superognathal. In its slender form and in having a broad, flat process, the element is somewhat suggestive of *D. newberryi*; but in the latter a well-marked secondary cusp is present, and the posterior margin of the tooth is not excavated for interlocking with the postero-superognathal. Moreover, as compared with a juvenile postero-superognathal of *D. newberryi* of about the same size, the present element is more slender, has a stronger angle between the tooth and the process portions, in profile view; and the inner face of the process is excavated, instead of being almost flat.

Dinichthys sp. (Mandible)

(Pl. 70, fig. 3)

A *Dinichthys* mandible of about the size of that of *D. curtus* was recently collected from the Chemung rocks near the city of Erie, Pa., by Mr. E. J. Armstrong, an engineer and student of invertebrate fossils. He has kindly presented it to the Buffalo Museum. This is the first *Dinichthys* mandible to be found in the Chemung, and it seems to differ somewhat from other *Dinichthys* mandibles, so much, in fact, that we believe when an example of it clear of matrix is obtained, it will probably turn out to be a new species, for which we would propose the name *D. Armstrongi* be reserved. As the specimen is embedded with its outer face in the rock so that the form of the functional region is not shown, and since the absence of the posterior extremity must leave it a little doubtful as to the exact length of the entire mandible, we deem it best not to name it at this time. The specimen may be described as follows:

E 2598 A left mandible (Pl. 70, fig. 3), in matrix, shown in inner view. The posterior end is lacking. The beak is rather more recurved than in *D. curtus* or *D. intermedius*. The second cusp also is rather farther back than in these species.

	cm.
Length as far as preserved	22
Estimated total length	26
Length of functional portion (measured to its junction with the blade portion)	13

Numerous fragments of *Dinichthys* plates have been obtained from the Chemung rocks—portions of crania, and dorsal and ventral plates—but, with one exception, all have been too fragmentary for description. There is a large series of such remains in the New York State Museum, at Albany, N. Y., the best of which were at one time sent to one of us (Hussakof) for study, through the kindness of Director John M. Clarke. Among them was one especially noteworthy—the left margin of a cranium about as large as that of *D. curtus*, or of a size to go with the present mandible. No doubt complete plates of this species will some day be found.

The mandible is too large to belong to *D. tuberculatus* Newberry, which is known only by a small antero-dorsolateral, ornamented with rather large, stellate tubercles.[21]

Regarding the locality and horizon at which the mandible was found, Mr. Armstrong has kindly supplied the following note:

"The locality is on the east branch of Twelve Mile Creek, in Greenfield Township, Erie County, Pa., 200 yards south of the township line. The layer from which it came is approximately 100 feet above the base of the Chemung. The shells on the slab are principally *Productella lacrymosa*, very poorly preserved. *Spirifer disjunctus*, *Camarotoechia contracta*, and *Leiorhynchus newberryi* are also present in this layer. All four species are plentiful both above and below this horizon—above, as far up as the strata are exposed; below, as far as the base of the Chemung. There are of course many other species, but they are not so persistent."

Dinichthys tenuidens, n. sp.

(Pl. 69, fig. 2)

E 2596 *Type.*—A small left mandible, in matrix, shown in outer view. Length, 67 mm.; depth, at end of functional portion, 10.

Formation and Locality.—Rhinestreet shale; Cazenovia Creek, near Willink, N. Y.

Mandible of small size, the functional portion more slender, i.e., not so deep, as the blade, or inserted portion. Functional margin occupying more than half the length of the element; with a slender, pointed beak anteriorly, and a second cusp, also large and pointed, about ⅖ the length of the cutting margin behind it; part of cutting margin between the two beaks, a sharp, almost straight cutting edge, and this portion of mandible more slender than part back of second cusp.

[*Tenuidens*, in allusion to the slender character of the mandible.]

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[21] Newberry, J. S.: *Paleoz. Fishes N. Amer.*, 98, pl. xxxii, fig. 3, 1889.

Remarks.—This small mandible constitutes a well-marked species, easily distinguished by the two widely-separated beaks, and the shallowness of the part of the mandible between them. It differs from all other dinichthyid mandibles by the fact that the cutting margin is longer than the blade, or inserted, portion (measured from its upper junction with the functional part). The mandible as a whole is also rather more slender than is usual in *Dinichthys*; but the presence of two beaks, precludes its being placed in *Stenognathus*.

The specimen may perhaps belong in the same species with the remarkable slender antero-superognathal described on a previous page under the name *Dinichthys insolitus*. But there is no proof of such association, and for the present it is wiser to consider this mandible a distinct species.

Dinichthys sp. (Ventral armor)

(Text-figs. 16, 17)

E 2032 The complete ventral armor of a medium-sized species of *Dinichthys*, on a slab of shale. The specimen is badly weathered, and much of the actual bone is lost; but the outlines of the plates can be made out, and at the posterior end, where the tip of the postero-ventrolaterals is missing, it can be supplied by continuing the outline of the portion of these plates preserved. The antero-ventromedian was obviously a separate plate and not fused with the postero-ventromedian into a single piece. To the right of the antero-ventrolaterals is a small plate, shaped somewhat like an upper tooth; it is, however, a thin plate and shows a centre of ossification. The fragment seen above the right antero-ventrolateral is a portion of an unidentified plate.

Total length of plastron 31 cm.; greatest width, 17.

Portage; Sturgeon Pt., on shore of Lake Erie. Collected by Mr. F. K. Mixer.

This is a very important specimen, being one of the two thus far known which show the entire ventral armor of *Dinichthys* in natural association. The other specimen is that of a small dinichthyid described in 1910 by Burnett Smith.[22] In this the plates were repre-

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[22] Smith, Burnett: Notes on some little-known fishes from the New York Devonian. *Proc. Acad. Nat. Sci.*, Philadelphia, lxii, 656–663.

sented only by their impressions in half of a small concretion. Two or three less complete ventral armors of *Dinichthys* are also known; first, that described by von Koenen[23] in 1895, in which the left half of the plastron is preserved; second, a much more complete armor consisting of an antero-ventrolateral and both postero-ventrolaterals, associated with other remains of a single specimen of *Dinichthys curtus*, described by Hussakof in 1905.[24]

The present specimen was discussed at some length in 1897 by Eastman,[25] who tried to determine the species from a consideration of the known relations in size between the mandible and the ventral plates in some dinichthyids. He conlcuded that the specimen might provisionally be referred to *D. newberryi*. But it seems to us, after a careful study of both the specimen and this discussion, that the matter is altogether too hypothetical for a definite conclusion, and that there is no use in this fine-spun reasoning since it cannot lead to anything *positive*. For our part, we are content to describe the specimen as a plastron of *Dinichthys*, without referring it to any one species. If *D. newberryi* were the only species of *Dinichthys* in the Portage shales, we would be justified in thinking that the present plastron belonged to it; but since there are one or two other species, as shown by fragmentary remains, there seems little justification for associating the plastron with one of these rather than with another. The discovery in the Portage of ventral plates in association with other remains may, at any time, upset any mere theoretical conclusions on this point.

Figure 16, represents the plastron as it appears in the slab, and figure 17, is a restoration of it. On comparing the two figures it will be seen that there is very little that is conjectural in our restoration. It is, in fact, hardly more than an outline drawing of the plates shown in the specimen, with here and there a missing portion of the outline added.

On comparing our restoration with that given by Eastman[26] of the same specimen it will be seen that there is considerable difference between the two. In our restoration the postero-ventrolaterals are broader and shorter, and united in the median line by small flanges

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[23] von Koenen, A.: Ueber einige Fischreste des norddeutschen und böhmischen Devons . . . *Abhandl. k. Gesell. Wissen.* Göttingen, xl, 1–37, pls. i–v.

[24] Hussakof, L.: On the structure of two imperfectly known Dinichthyids. *Bull. Amer. Mus. Nat. Hist.*, xxi, 409–414, pls. xv–xvii and 2 figs.

[25] Eastman, C. R.: On the relations of certain plates in the Dinichthyids, with descriptions of new species. *Bull. Mus. Comp. Zool.*, xxxi, 19–44, pls. i–v.

[26] Loc. cit., pl. i, fig. 2.

instead of merely overlapping to the extent of about one-fourth the width of one of these plates. The anterior median-ventral differs in shape; the postero-ventromedian does not extend so far back; and the anterior processes of the antero-ventrolaterals are shorter and broader, giving these plates a different aspect. We believe there is ample justification for all these details in the specimen.

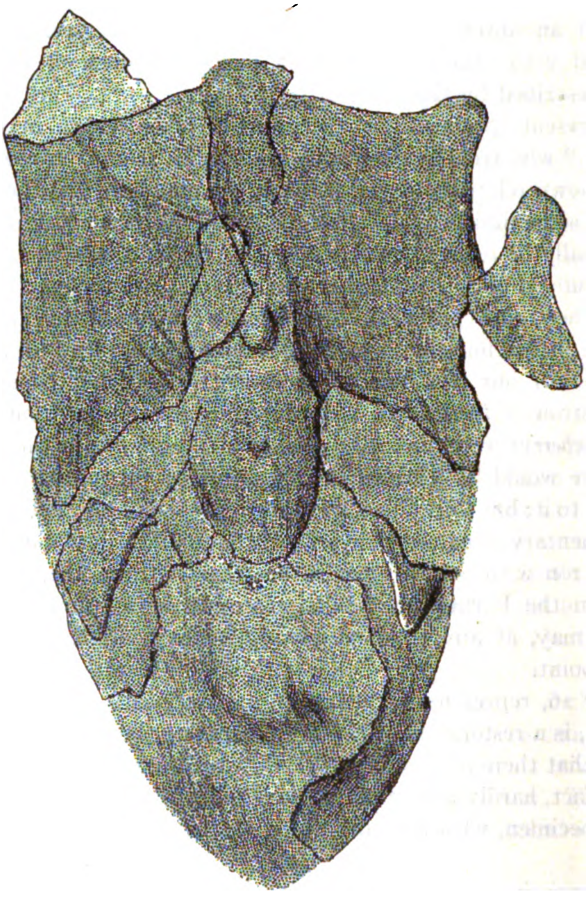

FIG. 16. *Dinichthys* sp. VENTRAL ARMOR OF A MEDIUM-SIZED SPECIES, MUCH WEATHERED. × ⅛. E 2032

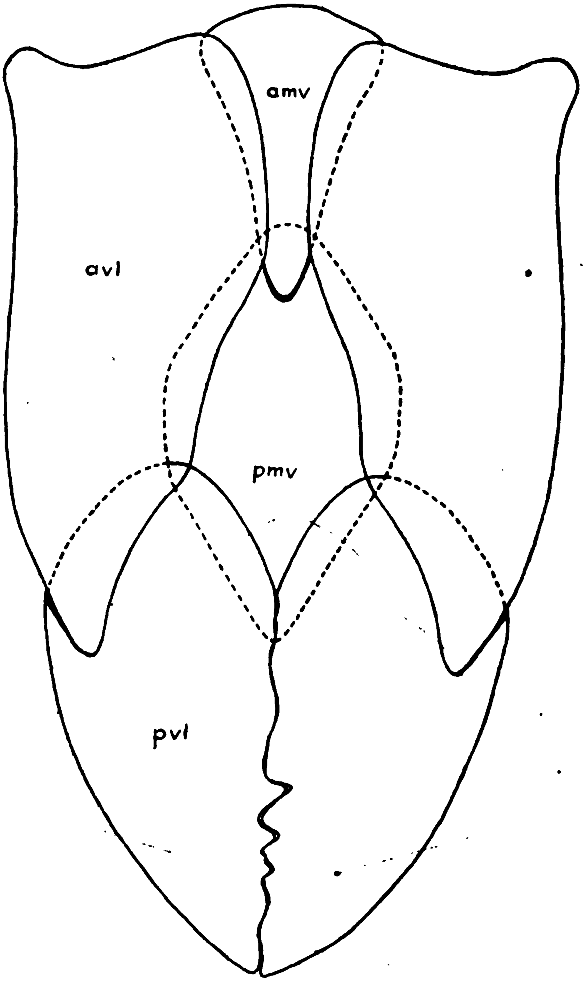

FIG. 17. *Dinichthys* sp. RESTORATION OF VENTRAL ARMOR SHOWN IN FIGURE 16. × ½

amv, antero-medianventral; ***avl***, antero-ventrolateral; ***pmv***, postero-medianventral; ***pvl***, postero-ventrolateral.

Dinichthys sp.

In addition to the specimens of *Dinichthys* referred to various species in the preceding pages, there are a considerable number of remains that are at present specifically indeterminable. Some of them no doubt belong to *D. newberryi*, others to *D. magnificus*, and a few perhaps represent juvenile individuals.

1. Specimens from the Conodont bed, (Genesee), at Eighteen Mile Creek, Erie County, N. Y.; collected by W. L. Bryant.

a. Cranial plates

E 1981 Rostral element of a small cranial shield (Pl. 17, fig. 1). It is ornamented with minute tubercles, much smaller than those of *Dinichthys pustulosus*, grouped partly into vermiculating, ridge-like rows. We have used this element as a guide in restoring the front of the head of *Dinichthys magnificus* in text-figure 9.

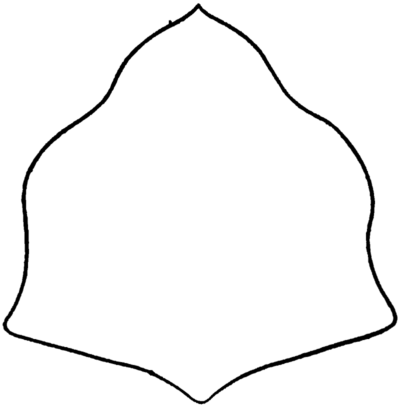

FIG. 18. OUTLINE OF A MEDIAN OCCIPITAL OF AN INDETERMINATE SPECIES OF *Dinichthys*. × ½. E 2008. (See Pl. 19, fig. 2.)

E 1994 External occipital showing sensory canal and articulating socket.

E 2008 Median occiptal. (Pl. 19, fig. 2; text-fig. 18). The ornamentation consists of fine tubercles with a linear arrangement, radiating from the centre of the plate, and recalling the ornamentation of *Holonema* (*Glyptaspis*) *abbreviatum*.

b. Suborbitals

E 1984 Anterior portion of a right suborbital, showing sensory canal; without ornamentation. The plate is comparable in size with its homolog in *Dinichthys newberryi*, and perhaps belongs to that species.

E 1992 Suborbital of a small dinichthyid.

E 2001 Imperfect suborbital showing sensory canal; ornamented with fine tubercles. It probably belongs to the same species as the preceding.

c. Mandibles.

E 2510 Functional portion of a right mandible of a species about the size of *D. newberryi* (Pl. 14, fig. 2). The blade portion is broken away and the oral margin is deeply excavated, probably through wear. The mandible seems to have belonged to an old individual. The beak, however, is sharp and prehensile; its outer surface shows the bevelling produced by the play of the antero-superognathal against it. The inner surface of the beak is hollowed out. It is therefore much weaker than most dinichthyid mandibular cusps, and in this respect and in its slender proportions the mandible resembles that of a very large *Stenognathus*.

E 1941 Beak of a right mandible.

E 1948 Portion of the cutting blade of a small mandible.

d. Antero-superognathals

E 1951 A very small left antero-superognathal (Pl. 18, fig. 1), the smallest element of the kind ever found. Its height is 8 mm.; width, 11. It is, of course, not known what species it represents.

E 1952 Two small right antero-superognathals, perhaps young of *Dinichthys newberryi*.

E 1954 A small right antero-superognathal which may represent a juvenile individual of *D. magnificus* (pl. 27, fig. 1). It differs from the juvenile antero-superognathal of *D. newberryi* in that the anterior face joins the outer lateral face in a sharp ridge, instead of the two being confluent in a convex plane as in juvenile antero-superognathal of the latter. The fang also is relatively sharper and more pointed. Height, 4 cm.

E 1958 "Tooth" of a left antero-superognathal of about the size of *D. newberryi* (Pl. 13, fig. 3. By inadvertance this figure is upside down.)

e. Postero-superognathals

The following two postero-superognathals are clearly referable to *Dinichthys*. They are small, but judging by the amount of wear of the functional margin, they both probably represent adult individuals. The inferior margin is in both strongly rounded; and they differ in form from any other postero-superognathals hitherto described. None the less, we hesitate to base a species upon them, since they may belong with some of the other *Dinichthys* remains for which we have proposed names in the preceding pages.

E 1943 A small right postero-superognathal, 65 mm. in width (Pl. 16, figs. 1, 1 a). The inferior margin is more rounded than is usual in *Dinichthys* postero-superognathals. The functional margin, on the inner face, is beveled by wear. Five denticles are present along the posterior end of the cutting margin, which increase somewhat in size distalward.

Measurements	mm.
Greatest width	65
Total height, including process	50
Greatest height from cutting margin to line separating lower from upper half	29

E 2388 A right postero-superognathal of the same species as the preceding but smaller; in matrix, shown in inner view (Pl. 16, fig. 2). Greatest width, 56 mm.; total height, including process, 36.

f. Dorsal and lateral plates

E 1998 Half of a postero-dorsolateral, ornamented with small, non-stellate tubercles on the non-overlapped portion (Pl. 13, fig. 5).

E 2004 Antero-dorsolateral of a small dinichthyid, finely tuberculated.

E 1991 Portion of a lateral or "clavicular" plate.

g. Ventral plates

E 1989 Portion of a small ventral plate, without ornamentation.

E 1990 Imperfect postero-ventrolateral (?) of a small dinichthyid, without ornamentation.

E 1993 Antero-ventromedian of a small dinichthyid.

E 2000 Ventral plate of a small dinichthyid, finely tuberculated.

E 2002 Ventral (?) bearing fine tuberculation; same species as preceding.

E 2389 A juvenile right antero-ventrolateral (Pl. 18, fig. 2). The plate is very thick for a specimen of such small size, but the same condition was observed by us in one or two other small specimens, and is, perhaps, a characteristic of juvenile ventral plates in some species. The outer face is ornamented with small non-stellate tubercles, which are especially well-shown on the posterior half of the plate, where the outer surface is well-preserved; on the anterior half of the plate, the external surface is somewhat abraded and no tubercles are preserved.

Length, 114 mm.; greatest width (slightly restored) 43; maximum thickness (at about one-third the length of the plate from the anterior margin and near the outer half), 13.

h. Fragmentary plates

E 1996 Incomplete plate of a small dinicthyid, ornamented with stellate tubercles rather larger than those of *Dinichthys pustulosus*. (Pl. 17, fig. 2).

E 1997 Fragmentary plate, ornamented with smaller tubercles than the preceding (Pl. 17, fig. 3).

E 2003 Finely tuberculated plate.

FIG. 19. CUSP, OR "TOOTH," OF RIGHT MANDIBLE OF A SMALL SPECIES OF *Dinichthys*, OUTER VIEW. NATURAL SIZE. E 2038

E 2011 Fin-ray (Pl. 18, fig. 3), resembling those figured by Newberry (*Paleoz. Fishes N. Amer.*, Pl. vii, fig. 1). The specimen is similar to one found in association with the type of *D. magnificus* and perhaps belongs in that species.

E 1987 A small, fragmentary plate without ornamentation.

2. Specimens from the Rhinestreet shale (Portage); shore of Lake Erie at Sturgeon Point, Erie County, N. Y.; collected by F. K. Mixer.

E 2035 An imperfect plate ornamented with fine tubercles arranged in linear series (Pl. 28, fig. 1). This is perhaps not *Dinichthys* but an allied genus.

E 2036 A small, incomplete antero-ventrolateral.

E 2038 Anterior extremity of a small right mandible, showing the beak and the secondary cusp back of it, in matrix, shown in outer view (text-fig. 19).

E 2511 A postero-ventrolateral apparently not quite complete. The specimen (Pl. 14, fig. 1) measures 11 cm. in length and 8 cm. in greatest width. The anterior margin is practically complete and shows the notch into which the antero-ventrolateral fitted. The specimen is of about the size to go with the complete Rhinestreet shale plastron described on page 56, and there seems little doubt that it belongs to the same species. It was collected at the same locality and horizon.

Titanichthys sp.

(Text-fig. 20)

E 2390 Slab in counterpart, exhibiting portion of a rather small lateral, or ''clavicular'' plate, and a second, complete but indeterminate plate partly overlying it.

Cleveland shale; Linndale, near Cleveland, Ohio; collected by W.L. Bryant, 1914.

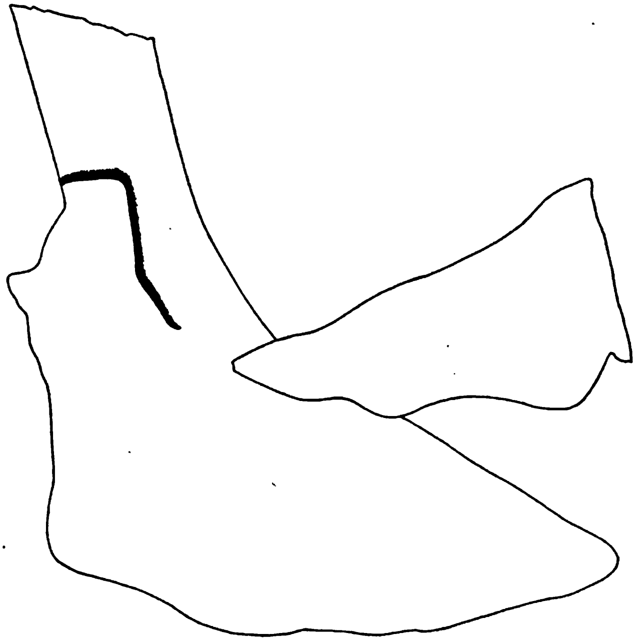

FIG. 20. *Titanichthys* sp. OUTLINE OF ONE ARM OF A LATERAL AND AN ASSOCIATED PLATE. × ½. PRESERVED IN COUNTERPART. E 2390

E 2391 Anterior third of a small right mandible (Pl. 19, fig. 1). In the same concretion and in actual contact with the mandible is a spiniferous plate, or fin-ray, with knife-like blade, similar to those of dinichthyids.

Stenognathus dolichocephalus (Eastman)

(Text-figs. 21, 22)

Dinichthys dolichocephalus C. R. Eastman, N. Y. State Mus., Mem. x, 135, pl. v, fig. 1, 1907.

The unique specimen by which this species is known is preserved in the Buffalo Museum (E 2034). It consists of a small slab of shale containing most of the armor plates and the mandibles of a small Arthrodire. The plates are more or less confused on the slab, most of

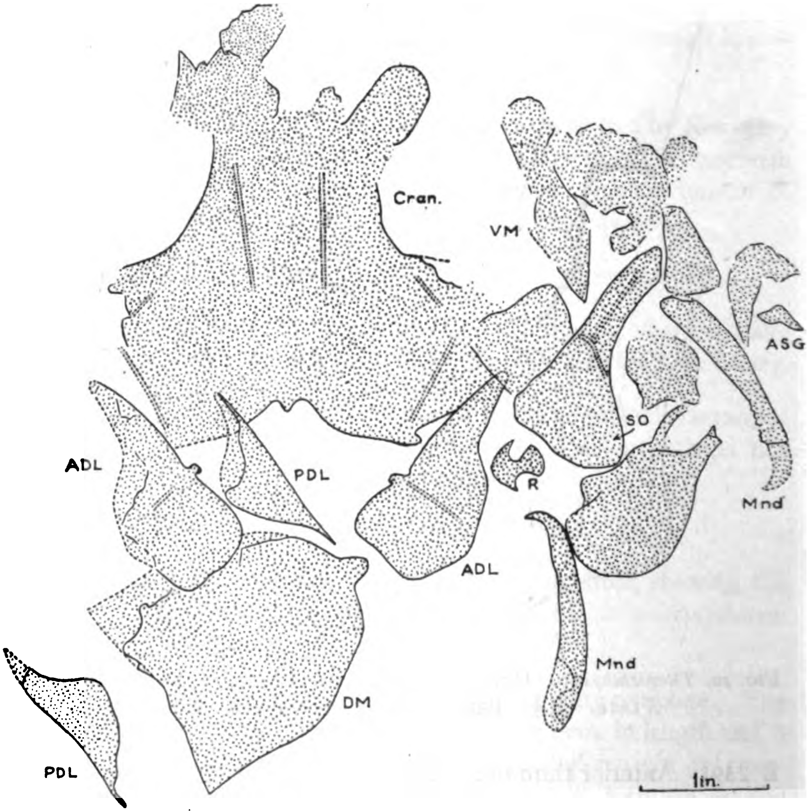

Fig. 21. *Stenognathus dolichocephalus* (Eastman). Type, × about ⅔. E 2034 Rhinestreet shale (Portage); Sturgeon Point, on Lake Erie, near Buffalo, N Y. *ADL*, antero-dorsolateral; *ASG*, antero-superognathal; *Cran*, cranium; *DM*, dorsomedian; *Mnd*, mandible; *PDL*, postero-dorsolateral; *R*, rostral; *SO*, suborbital; *VM*, ventromedian.

them are poorly preserved, and the actual bone is missing in places; still their outlines can in most cases be clearly made out. We have restudied the specimen, and made a careful tracing of it which is reproduced in figure 21. This represents all that can be made out; we have only omitted, for the sake of clearness, some hazy indications of plates, especially near the right margin of the dorsomedian.

The plates present in the specimen are: the cranial shield, dorsomedian, both antero- and both postero-dorsolaterals, both mandibles, one antero-superognathal (not mentioned in Eastman's description), a suborbital, a median ventral, and portions of several other plates, perhaps ventrals.

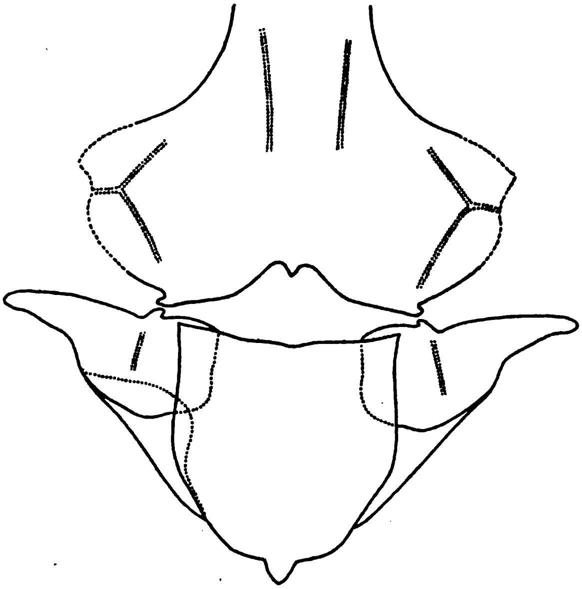

FIG. 22. *Stenognathus dolichocephalus* (Eastman). RESTORATION OF DORSAL ARMOR OF SPECIMEN SHOWN IN FIGURE 21

To determine the genus and species to which the specimen belongs, we must obviously look to the mandibles as the most distinctive elements of the animal. Fortunately these are fairly well-preserved. They are much elongated, and anteriorly rise into a beak. Eastman, in his original description of the specimen, decided that the mandibles were of the *Dinichthys* type, and referred the specimen to that genus.

To us, they appear too slender for *Dinichthys*, and rather like the slender mandibles named by Newberry *Stenognathus*.[27] This genus has recently been studied by Hussakof[28] on the basis of a fine specimen displaying most of the remains (including the dentition) of an animal in a concretion from the Cleveland shale, preserved in the British Museum. By the aid of this specimen it was shown that the form named *Dinichthys gouldi* by Newberry, the incomplete mandibles known as *Dinichthys corrugatus* and *Stenognathus corrugatus*, and the complete mandible described by Claypole under the name of *Dinichthys gracilis*, are all one form, to which Newberry's generic term *Stenognathus* is applicable. This genus is especially remarkable for its long, slender mandibles and its elongated posterosuperognathal.

If we compare the mandibles of the Buffalo specimen under discussion (E 2034), with those of *Stenognathus*, we see that they are of the same type, thus proving that this specimen belongs in that genus. Moreover, there is a correspondence in other plates which are distinctive for the genus,—for instance, the suborbital, which is roughly triangular, rather than rectangular as in *Dinichthys*. For these reasons it is clear that the specimen belongs in *Stenognathus*.

The specimen was collected by Mr. F. K. Mixer from the Portage, at Sturgeon Point, on the shore of Lake Erie, near Buffalo, N. Y.

Stenognathus ringuebergi (Newberry)

(Pl. 15, fig. 2, Pl. 69, fig. 1)

Dinichthys minor RINGUEBERG, Amer. Journ. Sci., 3 ser., xxvii, p. 476. 1884.
Dinichthys ringuebergi NEWBERRY, Pal. Fishes N. Amer., p. 60. 1889.

This species has hitherto been known only by the type specimen, a dorsomedian plate, in the collection of Mr. E. N. S. Ringueberg, of Lockport, N. Y. We may now record a second specimen collected by Mr. Bryant in the summer of 1916, which very materially increases our knowledge of this form.

Through the kindness of Mr. Ringueberg we have had the privilege of studying and photographing the type plate, and we here give an account of it in the light of present knowledge of this group.

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[27] *Trans. N. Y. Acad. Sci.*, xvi, 30, pl. xxiv, figs. 27–28, 1897.

[28] Hussakof, L.: Upper Devonian Arthrodira from Ohio in the British Museum (Natural History). *Geol. Magazine*, [5], viii, 126, pl. viii, fig. 5 and text-fig. 6, 1911.

A detailed description of the plate accompanied by a pen-and-ink figure was published by Ringueberg in 1884.[29] The plate was correctly identified as a dorsomedian, but was figured upside down—an error excusable at that time when so little was known concerning *Dinichthys* and so few figures were available.

The plate is well represented in Plate 15, figure 2. It is of small size, 11 cm. in length in the middle line (without the process), and 14 cm. in greatest width. Its most distinctive character is the emargination of the front halves of the lateral margins. In this, however, it is not unique, for a dorsomedian of much larger size, from the Cleveland shale, in the American Museum collection, shows the same form. This feature distinguishes these two plates at a glance from dinichthyid dorsomedians. It is possible that the plate belongs to the species we have named *Stenognathus mixeri* (page 75); it is of about a size to go with the type of the latter. However, ventral plates of the latter show a fine tuberculation which is not evident in *S. ringuebergi*. The fact that a similar shaped plate occurs in the Cleveland shale is interesting in view of the occurrence of *Stenognathus* in that formation also.

The plate is embedded in matrix and displays the dorsal, or upper surface. The extremity of the keel, forming the usual dinichthyid "knob" process, is well shown.

Horizon and locality.—Portage shale (Rhinestreet): Sturgeon Point, shore of Lake Erie, N. Y. Collected by Mr. E. N. S. Ringueberg and preserved in his private collection at Lockport, N. Y.

Besides the type just described, we have in hand a remarkable specimen of this species collected by Mr. Bryant in the summer of 1916. The specimen is of great interest for the fact that it shows a part of the notochord, with neural and haemal arches. It is the second specimen of a *Stenognathus* found with the notochordal region preserved. Although no dental elements are preserved in the specimen, still we regard it as belonging to the genus *Stenognathus*, for the reasons that the form of the dorsomedian— especially as shown in the type—excludes it from the genus *Dinichthys*; but the thinness of the ventral plate, coupled with the fact of its size and resemblance to its homolog in *S. gouldi*, would indicate that the specimen belongs in *Stenognathus*.

E 2595 The specimen (Pl. 69, fig. 1), consists of a slab of shale, 65 by 37 cm., displaying the dorsomedian (*DM*), a postero-

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[29] Ringueberg, E. N. S.: A new *Dinichthys* from the Portage Group of Western New York. *Amer. Journ. Sci.*, 3 ser., xxvii 476–478, 2 figs.

ventrolateral (*V*), with some fragments apparently of other ventral plates, and, behind these, a part of the notochordal area (*N*) delimited by neural (*n.a.*) and haemal (*h.a.*) arches.

The *dorsomedian* is shown in outer view. Its anterior margin, and the front portion of the right side are gone, but the left side shows the anterior emargination, so characteristic of this species (see figure of type, Pl. 15, fig. 2), and at once enables us to identify the form as *S. ringuebergi*. The posterior process of the plate is also preserved.

The *postero-ventrolateral* present is that of the right side, shown in outer view. It is very thin, thinner proportionally than in a *Dinichthys* of the same size, and where the bone has weathered away, the impression in the matrix shows rings of growth.

The *notochord*—or more properly, the space occupied in life by the notochord—is preserved for a length of 29 cm. It measures 40 mm. in diameter near the anterior end of the preserved portion, and does not, in this portion, at any rate, decrease much in diameter; at the posterior end of the preserved portion it is 35 mm. in diameter. The neural and haemal spines (arches?) are not sharply preserved, although it is seen at a glance that one set, evidently the neural spines, are higher than those of the opposite side, the haemals. This notochordal region resembles that frequently found in specimens of *Coccosteus* from the Old Red Sandstone, except, of course, that it is broader, as it should be in an animal much larger than *Coccosteus*.

The only other example of the notochord in a dinichthyid, is one collected years ago in the Cleveland shale of Ohio, and preserved in the American Museum in New York. This, also, apparently belongs in the genus *Stenognathus*.[30]

Horizon and locality.—Rhinestreet Shale; Eighteen Mile Creek near Hamburg, N. Y. Collected by W. L. Bryant, 1916.

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[30] No. 2454 Amer. Mus. *Trans. N. Y. Acad. Sci.*, xv, 157, pl. vii, 1896.

Stenognathus gouldi? (Newberry)[31]

(Pl. 15, fig. 1)

E 2392 Anterior half of a right mandible with the beak and cutting edge well preserved. Length, as far as preserved, 82 mm. Height at middle of functional region, 29.

This specimen seems referable to *S. gouldi* (Newberry), of the Cleveland shale of Ohio. It agrees with this form in size and in absence of the symphyseal denticles, the latter present in *S. insignis* and *S. mixeri*, two new species described farther on. If the identification is correct then this species is common to the Cleveland shales and the Conodont bed.

Conodont Bed (Lower Genesee); Eighteen Mile Creek, near North Evans, Erie County, New York.

Stenognathus denticulatus, n. sp.

(Text-fig. 23)

E 2386 *Type.*—A small right postero-superognathal with upper part of outer face covered with matrix; inner face clear. Width 41 mm.; total height, including process, 17.

Formation and Locality.—Conodont bed (Genesee), Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Postero-superognathal small, elongated, its distal half gradually tapering toward the posterior extremity. Outer face ornamented with four or five downward-pointing denticles extending in a row diagonally upward and backward from the middle of the cutting margin; denticles separated from one another by spaces equal to, or exceeding, the width of a denticle, and covered with a shining, enamel-like substance. Inner face concave, except in region of articulating process, which forms a low, rounded, but prominent ridge.

Remarks.—This element is clearly distinct from any other hitherto described. Its elongation antro-posteriorly seems to us to place it in *Stenognathus* rather than *Dinichthys*. The presence of ornamental denticles on the outer face is a very remarkable feature, such

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[31] For full synonymy and description of this species see paper by Hussakof referred to in footnote 28, page 68.

a condition being known in only a few Arthrodira, and in none of them being better shown. The form with which the element can best be compared as regards this feature is *Dinichthys herzeri*, in which the postero-superognathal has a row of ornamental denticles extending diagonally upward across the outer face very much as in the specimen here described.[32] This species is, however, of huge size as compared with the present specimen, and also, the postero-superognathal is not so elongated.

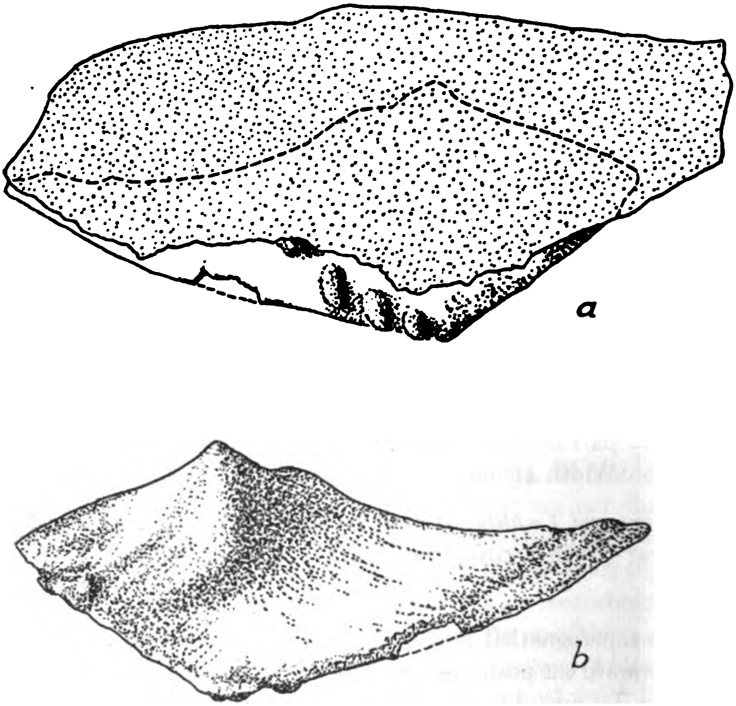

FIG. 23. *Stenognathus denticulatus*, n. sp. RIGHT POSTERO-SUPEROGNATHAL. TYPE, × 2

a, outer view showing the oblique row of denticles. Most of this side of the element is covered with matrix, indicated by the stippling. *b*, inner view. E 2386.

From its homolog in *Stenognathus mixeri* described on p. 75, it is distinguished by its relatively greater elongation and by tapering more to a point in its distal half.

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[32] For a figure of the postero-superognathal in *Dinichthys herzeri* see Hussakof, L.: Studies on the Arthrodira. *Mem. Amer. Mus. Nat. Hist.*, ix, pl. xiii, fig. 3, 1906.

Stenognathus insignis, n. sp.

(Pl. 21, fig. 2, and text-fig. 24)

E 1932 *Type.*—A right mandible lacking the posterior half of the inserted portion.

Measurements	mm.
Length of functional portion, including beak	80
Depth at middle of functional area	24
Depth of blade portion (2 cm. back of functional part)	25

Formation and Locality.—Conodont bed (Lower Genesee); Eighteen Mile Creek, near Buffalo, N. Y. Collected by W. L. Bryant.

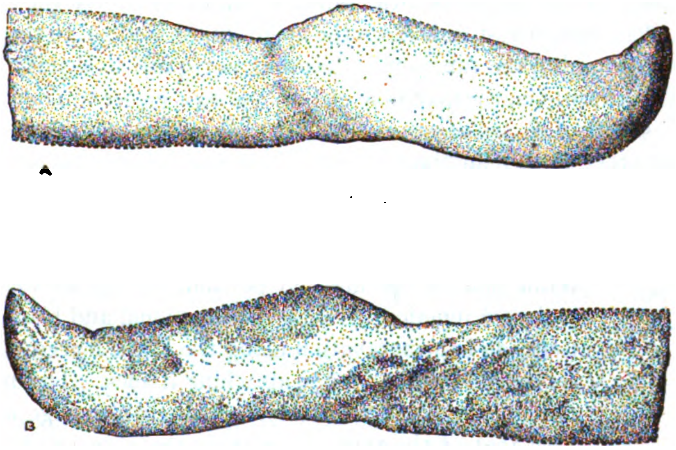

FIG. 24. *Stenognathus insignis*, n. sp. RIGHT MANDIBLE. TYPE, × ¾ *A*, outer, and *B*, inner views. E 1932. (See Pl. 21, fig. 2.)

Mandible long and slender, with the anterior functional portion demarcated from the nonfunctional as in *Dinichthys*. A prominent dinichthys-like beak present, but no secondary beak or cusp back of it. Functional margin a continuous knife-like edge, rising gently backward to near the point of its union with the nonfunctional portion of mandible, whence it slopes more abruptly down to merge in the blade portion. Posterior end of functional margin without denticles. Inner face of functional area thins out gradually toward the cutting edge, except near middle of this area, where there is a faint indication of a ridge rising obliquely upward and forward; this does not, however, rise above the cutting edge so as to form a secondary cusp, as in *Dinichthys*. Symphyseal denticles present (not well-shown in the type).

Remarks.—Besides the type we have three other specimens of this species, from the type locality. In general shape, and in the demarcation of the functional from the inserted portion, these elements are not unlike a *Dinichthys* mandible. But the long, slender form, and the absence of a secondary cusp back of the beak, clearly mark them as belonging to the genus *Stenognathus* as defined by Newberry.

From *Stenognathus gouldi*, the Ohio species, the present form is disguished, first, by the much weaker beak; second, by the presence of symphyseal denticles, whereas in the Ohio species their place is occupied by a rounded vertical ridge, which extends, like the row of denticles, about two-thirds down the height of the blade. In the present species, also, the functional portion is not quite so slender as in the Ohio form; i.e., the mandible of this species is closer to *Dinichthys* than is that of *S. gouldi*.

The other three mandibles of this species (*paratypes*), are from the type formation and locality:

E 1933 An imperfect left mandible, lacking the beak and the posterior half of the inserted portion. It shows well the region of junction between the functional and blade portions, and the excavation along the lower margin of the functional portion for the attaching tissues. This region resembles that in *Dinichthys*. The cutting edge agrees with that of the type specimen in the absence of a secondary cusp.

E 1938 Anterior portion of a mandible. The specimen is somewhat deeper than the type and probably represents an older individual. It shows the symphyseal region well; this is turned inward at right angles to the outer face and terminates in a vertical row of denticles, extending about two-thirds down the symphyseal margin. The denticles themselves are missing, but the roots of two of them are clearly shown; the lowermost one is the largest.

E 2506 Inserted portion of a mandible.

Stenognathus mixeri, n. sp.

(Text-fig. 25)

E 2030 *Type.*—A slab of shale 29 by 46 cm., in counterpart, containing both mandibles, an antero- and a postero-superognathal, both suborbitals, portion of a lateral plate, sclerotic segments, and several incomplete cranial and ventral plates.

Formation and Locality. Rhinestreet shale (Portage); shore of Lake Erie, near Sturgeon Point, Erie County, New York. Collected by F. K. Mixer and W. L. Bryant.

Mandible 17.5 cm. in length, long and slender, the functional portion contained 1⅓ times in the blade portion; greatest depth of functional portion 3½ times in its length. Functional margin with denticles except at its anterior fourth, which is smooth and beveled; denticles about 12 in number, gradually increasing in height backward; largest denticle 3 mm. high. Anterior extremity of mandible rises into a low beak. Symphysis with a vertical row of 7 denticles. Antero-superognathal triangular in outline, with a pointed beak and a small, secondary cusp; upper or process portion of element flattened, thin and not developed into an elongated thickened process as in *Dinichthys*; outer lateral margin of element with 4 or 5 low denticles. Postero-superognathal, elongated, and when found, had a row of denticles along its functional margin. (This element is shown in inner view and is not well preserved.) Plates of cranial shield apparently thin. Suborbital of the form characteristic of this genus, with long slender anterior process and relatively short, somewhat triangular blade portion. Orbit very large.

We take pleasure in naming this species for Mr. F. K. Mixer of Buffalo, long an active member of the Buffalo Society and at one time curator of its museum, to whom students of Arthrodira are indebted for his discovery of numerous localities of fish-bearing rocks in the vicinity of Buffalo. Mr. Mixer and Mr. Bryant were together on a collecting trip at Sturgeon Point, N. Y., when the present specimen was discovered.

Remarks.—This remarkable specimen belongs in the genus *Stenognathus*, a genus distinguished especially by its long, slender mandibles, sub-triangular antero-superognathals, and elongated upper shear teeth. The suboribtals are also characteristic, the orbits being large, the anterior processes long and slender, while the plate proper is somewhat triangular, rather than quadrangular as in *Dinichthys*.

The type is well illustrated in figure 25. Only the elements referred to in the description above are illustrated, several confused, thin cranial or ventral plates on the slab, to the right of these elements, being omitted. These plates show in places an ornamentation of very fine tubercles. The specimen is preserved in counterpart, but as the bone was much shattered and partly lost in opening the concretion, it was completely dug out leaving only the impression; from this a

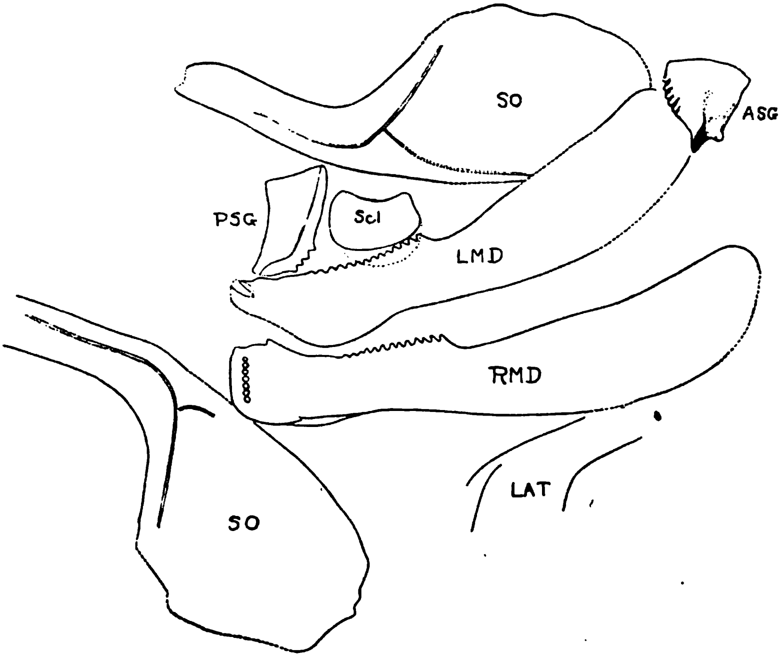

FIG. 25. ***Stenognathus mixeri***, **n. sp. OUTLINE OF ELEMENTS SHOWN IN TYPE SPECIMEN. × ABOUT ⅓**

The specimen is preserved in counterpart. E 2030. Rhinestreet shale (Portage); Sturgeon Point, on Lake Erie, near Buffalo, N. Y.

ASG, antero-superognathal, in outer view; *LAT*, lateral (or "clavicular"); *LMD*, left mandible, outer view; *PSG*, left postero-superognathal, inner view; *RMD*, right mandible, inner view; *Scl*, segment of the sclerotic ring; *SO*, suborbital—the one above is that of the left side, in outer view; the one below is that of the right side, also in outer view.

careful cast of each half was prepared, showing the elements in relief. The drawing is made from the cast of the better half of the specimen.

Both *mandibles* (Mnd), are preserved; the left is shown in outer view and the right in inner. Both show well the denticles along the functional margin, and the right shows also the row of symphyseal denticles. These are broken away and represented only by their bases.

Both *antero-superognathals* (ASG) are preserved, although the drawing shows only that of the right side, in outer view. This is one of the most interesting antero-superognathals known, showing the structure of this element in the genus *Stenognathus* better than any other specimen. In the specimen of *Stenognathus gouldi* in the British Museum, figured by Hussakof in 1911,[33] an antero-superognathal is preserved, which is somewhat similar to the present one in size and form; but it is not well enough preserved to show all its characters. The present specimen is therefore of great value, as showing for the first time the complete element in this genus. Its form and peculiarities are described above.

Only the left *postero-superognathal* (PSG) is present, shown in inner view. It is not very well preserved. When collected it had a row of denticles along its cutting margin.

Both *suborbitals* (SO) are present, shown in outer view. They have long, slender processes, and the blades proper are very thin and somewhat shorter posteriorly than in *Dinichthys*. The lateral canals are clearly shown.

Below the pair of mandibles is seen a fragmentary plate (LAT) probably a portion of one of the laterals.

This is the fifth species of *Stenognathus* to be described, and it is easily distinguishable from the others. From *S. gouldi* of the Cleveland shale, and from *S. insignis* of the Conodont bed (see p. 73), it is distinguished at once by the presence of denticles along the cutting margin of the mandible, in these two species the cutting margin being a continuous beveled edge. From *S. dolichocephalus*, which is from the same horizon and locality, it differs by its much larger size and by differences in the form of the various plates. From *S. denticulatus* of the Conodont bed (see p. 71) it is distinguished by its larger size and by the different form of the postero-superognathal.

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[33] Hussakof, L.: Upper Devonian Arthrodira from Ohio in the British Museum (Nat. Hist.). *Geol. Mag.*, [5], viii, 123–128, pl. viii, and text-fig. 6, 1911.

Stenognathus insignis?

E 1957 A small left antero-superognathal which from its size, texture of the bone, and the fact that the tooth is rather weak and might have functioned against just such a beak as that of the *Stenognathus insignis* mandible (fig. 24), we deem it probable that the specimen belonged to that species. The element is small: height, 25 mm., greatest width, 12. The point of the tooth is slightly reflexed upward and outward, and the articulating process is broad, flat and narrowly elliptical in cross-section—not subcircular as in *Dinichthys*.

Conodont bed, (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y.; collected by W. L. Bryant.

Selenosteus sp.

(Text-fig. 26)

This genus is indicated by two imperfect mandibles and several fragmentary armor plates from the Rhinestreet shale (Portage), at Eighteen Mile Creek. So far as we are aware, this is the first record of the occurrence of *Selenosteus* in New York state.

In this genus the head and armor plates are very thin, the dentition feeble, and the remains seem to have been tossed about a good deal and to have become broken or abraded before fossilization. It is one of the rarest of all American Arthrodires.

The mandibles described below are very close to those of *Selenosteus brevis* (Claypole)[34] from the Ohio shale, but are of smaller size. They are not completely enough preserved to allow of a detailed comparison with the mandibles of this species, so that we are not certain whether they represent this or a distinct form. On the other hand, as there are no body plates in our material that can positively be said to belong with these mandibles, there is at present insufficient ground on which to base the description of a new species. It seems probable that when better known this form will turn out to be new.

E 2393 A small left mandible, lacking the anterior, functional portion (fig. 26, *a*). It is represented mostly as an impression

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[34] For synonymy of this form see Hussakof, L.: Upper Devonic Arthrodira from Ohio in the British Museum (Nat. Hist.). *Geol. Mag.*, [5], viii, 123–128, pl. viii, 1911.

in shale, except at the posterior extremity where the actual bone is present for a length of 11 mm. In form this mandible agrees well with that of the type species, *Selenosteus brevis*, but is only about half its size. The bone is very thin and bears fine striations similar to those of the type species. Length, as far as preserved, 43 mm.

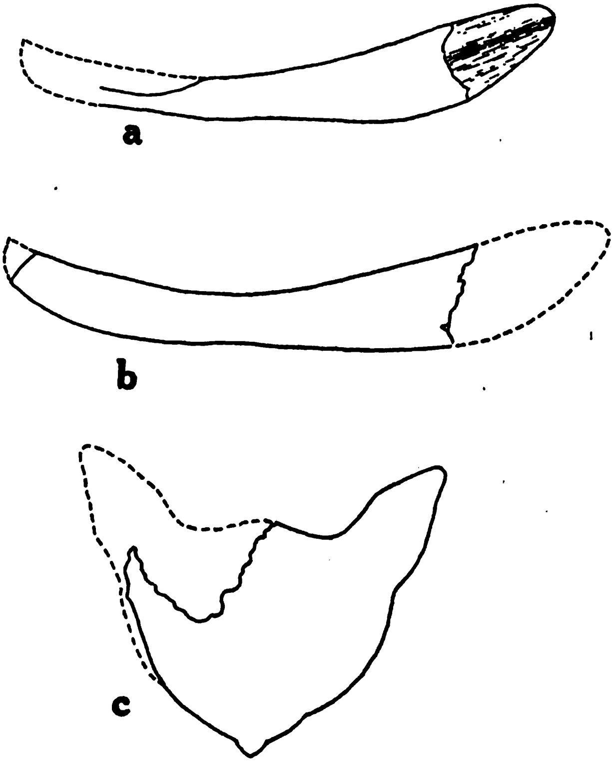

Fig. 26. *Selenosteus* sp. × 1½. Rhinestreet Shale (Portage); Eighteen Mile Creek, N. Y.

a, Left mandible.—E 2393. *b*, left mandible.—E 2394. *c*, dorsomedian.—E 2396.

Rhinestreet shale (Portage); from Eighteen Mile Creek, near Hamburg, Erie County, N. Y. Collected by W. L. Bryant.

E 2394 A left mandible, somewhat larger than the preceding, lacking the beak and the posterior extremity of the blade (fig. 26,*b*). The greater portion of the functional area is preserved, but no teeth such as are present in the Ohio species are to be seen. The specimen is on shale, and shown in outer view. The bone is thin and finely striated like the preceding specimen.

Formation and locality, same as preceding.

In addition to these mandibles, there are several other remains of a small Arthrodire which perhaps also belong to *Selenosteus*; the reference seems the more probable since they are mostly from the same formation and locality as the mandibles.

E 2395 A small cranial plate. From the thinness of the bone and the occurrence of the specimen in the same formation and at the same locality as the two preceding, we refer it provisionally to *Selenosteus*.

Other data same as preceding.

E 2396 A small dorsomedian shown in outer view, on a piece of shale (fig. 26, *c*). The plate is relatively short and broad, resembling a miniature *Titanichthys* dorsomedian. It bears an ornamentation of small, low tubercles, which are more or less fused on the median portion, but relatively few and scattered on the lateral portion of the plate. Length, 28 mm.; span across anterior angles, 32.

This element probably represents a small species of *Selenosteus*. However, since the left antero-lateral angle is missing, and the front margin appears somewhat frayed, as if broken, we hesitate to base a species upon it, since it perhaps represents a *Coccosteus* dorsomedian, of which the anterior half has been broken away. The resemblance of the element to a *Selenosteus* dorsomedian, depends chiefly on the fact that the front margin is strongly emarginate, the antero-lateral margins being produced into prominent angles. The posterior extremity of the plate is rather thickened and short; if it was drawn out to a point, as in *Coccosteus*, the point has been lost.

Other data same as preceding.

E 2022 Impression of three small ventral plates on a piece of thin shale (Pl. 29, fig. 1). On the reverse of the small slab is a fragment apparently belonging to the same individual, ornamented with fine tubercles. None of these plates shows the entire outline, but there can be no doubt that they belong to a small Arthrodire, probably *Selenosteus*, their size, thinness and texture being suggestive of this form.

Genundewa limestone (Genesee); Eighteen Mile Creek, Erie County, N. Y., collected by W. L. Bryant.

Perissognathus aduncus, n. gen., n. sp.

(Pl. 20, figs. 1, 1a, 1b; Pl. 27, figs. 4, 4a)

E 2397 *Type.*—Functional half of a right mandible, in matrix; shown in outer view. Length, as far as preserved, 78 mm.; height at beak (about 1 cm. restored), 53.

Formation and Locality.—Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Mandible consisting of functional and blade portions (the latter missing in the type specimen). Functional portion a little more than twice as long as the depth at its middle; oral margin a cutting edge, with a pronounced anterior beak; behind this beak a depression formed by the opposing antero-superognathal; and back of this, an obtuse secondary cusp. Symphysis a smooth, almost flat face bent inward at nearly right angles to the outer face of the mandible; its inner margin ending in a row of 7 or 8 teeth, which lie in the plane of this face and are directed obliquely upward at an angle of about 45°; toothed portion of symphysis extending two-thirds down the height of the blade, the symphyseal area below it being a more or less smooth, convex surface. The symphyseal area shows at its upper end, lines of wear which extend parallel to the axis of the beak.

[*Perissos*, extraordinary, wonderful; *gnathos*, jaw. Specific name, *aduncus*, bent in, in allusion to the inrolling of the symphyseal region.]

Remarks.—This remarkable mandible clearly represents an Arthrodire of a new genus. The species is represented in the collection by the type and by a beak of a mandible (E 2165) of about the same size as the type, which shows a similar symphyseal region and symphyseal teeth. In the type the blade or inserted portion of the mandible is missing, but a small projection of bone on the lower surface near the posterior end of the specimen apparently represents the blade portion and shows that it was present.

The most remarkable character of the mandible is, of course, the symphyseal region, with the 7 symphyseal teeth. These are so clearly shown (Pl. 20, figs. 1a, 1b) as to leave no question as to their number, size, form or direction. The symphyseal region has much resemblance to the denticled symphysis of *Coccosteus*, as shown for the latter in the few specimens in which it is preserved; but the symphyseal teeth in *Perissognathus* being so much larger are far better shown than in any specimen of *Coccosteus*.

There has been considerable discussion of the meaning of the symphyseal denticles in arthrodiran mandibles, and reference may be made to the detailed study of the subject by Hussakof, in 1906.[35] The present mandible throws some light on the problem. In the first place, the upper part of the symphyseal area shows lines of wear parallel to the axis of the beak, produced by the upper tooth. Had the two halves of the lower jaw been united at the symphysis it is inconceivable how an upper dental plate could have played against the symphyseal area on each side, and the two halves of the lower jaw still remain united. Secondly, the direction of the symphyseal teeth, which do not stand at right angles to the inner vertical margin of the symphyseal area but slant upward at an angle of about 45°, shows that these teeth could not have interdigitated; it is a mechanical impossibility for the symphyseal teeth to interlock unless they stood at right angles to the vertical margin of the symphysis.

It may be mentioned that the mandible of *Perissognathus* is also somewhat suggestive of a *Palæomylus* dental plate—at any rate, in its present form, with the hinder blade lacking. It thus serves like several other forms that might be mentioned to connect the Ptyctodontidæ with the Arthrodira, and so lends support to the view set forth by Dollo, in 1907, in his paper, "Les Ptyctodontes sont des Arthrodères."[36]

The following specimen also belongs to *Perissognathus aduncus*. It is from the same formation and locality as the type—Conodont bed, Eighteen Mile Creek—and was collected by W. L. Bryant.

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[35] Studies on the Arthrodira. *Mem. Am. Mus. Nat. Hist.*, ix, 118, 121, 122, *et passim*, 1906.

[36] *Bull. Soc. Belge de Geol.*, xxi, 12 pp., pl. ii.

E 2165 Beak of a left mandible of about the same size as the type (Pl. 27, figs. 4, 4a). It shows well the symphyseal denticles; these are six in number, are directed upward at an angle of 45°, and extend about half way down the symphysis. The area below them is undenticled and outwardly rounded. The bases of the 6 denticles occupy a space of 21 mm.

Machærognathus woodwardi, n. gen., n. sp.

(Pl. 21, figs. 1, 1a, 1b; text-fig. 27)

E 1935 *Type.*—A right mandible, lacking the posterior extremity. Length as far as preserved, 165 mm.; depth at middle of functional area, 30; height of beak, 27.

Formation and Locality.—Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Mandible long and slender, the blade portion apparently much shorter than the functional portion. Oral margin a cutting edge without denticles, worn on the outer face as in *Dinichthys*; with a strong beak directed upward and outward in a straight line and not recurved. Depression between beak and beginning of sectorial edge, broad and shallow. No secondary cusp back of the beak. Functional portion not sharply demarcated from blade portion but gently merging into it. Depth of functional area at its middle, contained about 3⅔ times in its length. Mandible viewed from above, slightly sigmoidal in section, its front half rather strongly convex outward.

[*Machairos*, knife; *gnathos*, jaw.]

We take pleasure in dedicating this species to Dr. Arthur Smith Woodward, Keeper of the Department of Geology in the British Museum, as an expression of admiration for his work in paleichthyology, as well as a token of appreciation of the many courtesies shown to the authors on their respective study visits to the British Museum.

Remarks.—This mandible differs from that of *Dinichthys* and all other arthrodires by the unusual length of the functional portion as compared with the inserted portion, and by the form of the element as a whole. The blade, or inserted portion, is not completely preserved, but even considering the greater portion of it to be missing, or indeed that when complete it was as long as the functional portion, we still have a mandible of very distinctive appearance and unlike that of any other known arthrodire. It represents a dolichocephalic type of arthrodire, comparable in this regard with *Stenognathus*. It resembles this genus also in the absence of the secondary cusp of the mandible. It also has some resemblance to the mandible of *Diplognathus*.

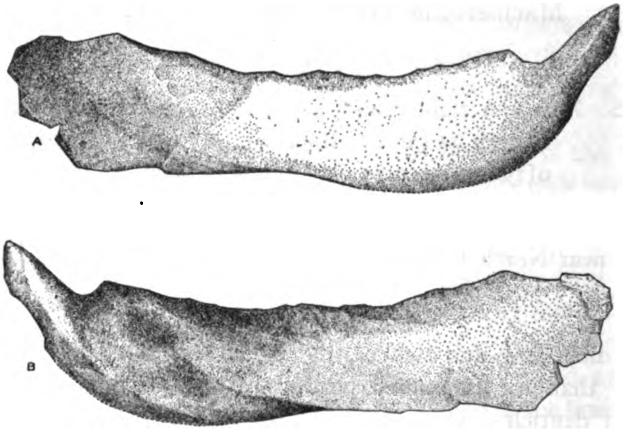

FIG. 27. *Machaerognathus woodwardi*, n. g., n. sp. RIGHT MANDIBLE, LACKING POSTERIOR EXTREMITY. × ½

A, outer view; *B*, inner. Type. E 1935.

Copanognathus crassus, n. gen., n. sp.

(Pl. 22, figs. 2, 3, 4; text-fig. 28)

E 1944 *Type.*—Left mandible. Length, 175 mm.; depth at middle, 55; length of tritoral area, 68.

Formation and Locality.—Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Mandible resembling that of *Dinomylostoma*; with a tritoral area occupying about $\frac{2}{5}$ of its length; straight fore-and-aft, not sigmoid; outer face convex, inner almost flat. Functional area not demarcated either on outer or inner face from the blade portion. Tritoral area widest at about its middle, thence gradually narrowing backward to its point of union with the blade portion; in side view rising gently upward toward the anterior extremity, which is formed into a blunt beak. Depth at middle of mandible contained a little over three times in its total length.

Kopanon, an axe or chopper; *gnathos*, jaw. *Crassus*, dense, in allusion to the dense and robust appearance of the element.]

Remarks.—This mandible has a certain resemblance to both the Dinomylostomid as well as the Ptyctodont type of mandible; and we have hesitated as to which to refer it. But in view of the fact that the tritoral area is situated in front, and also because of the form of the element as a whole, and of its microscopic structure which shows typical bone cells, it is more suggestive of an Arthrodiran than a Palæomylid mandible. We are inclined therefore to regard it as an arthrodire and allied to the genus *Dinomylostoma*. From this it is easily distinguishable by its straightness fore-and-aft—*Dinomylostoma* being decidedly sigmoid in cross-section, with the front half of the element convex outward—and by the form of the blade portion, which is relatively deeper near the posterior end. It may also be noted that there is no demarcation between the front and hind halves of the element, as in most species of *Dinomylostoma*.

FIG. 28. *Copanognathus crassus*, n. g., n. sp. LEFT MANDIBLE, × ⅓
A, from above; *B*, from inner side. Type. E 1944.

Dinomylostoma buffaloensis, n. sp.

(Pl. 23, fig. 1; pl. 24, figs. 1, 2, 4, 5; text-fig. 29)

E 1961 *Cotypes.*—(1) A right mandible lacking posterior half of the blade or inserted portion, free from matrix. Length as far as preserved, 106 mm. (Fig. 29; Pl. 24, fig. 1.)

E 1965 (2) A left mandible, lacking only the extreme end of the blade portion. The entire inner face, as well as the greater portion of the outer, are clear of matrix. Length as far as preserved, 136 mm. (Pl. 24, fig. 2.)

Formation and Locality.—Conodont bed (Genesee); Eighteen Mile Creek, near North Evans railroad bridge, Erie County, N. Y. Collected by W. L. Bryant.

Functional portion occupying about ⅓ the length of the mandible, and not demarcated on outer face from inserted portion. Oral morgin, in outer view, strongly concave, rising rather abruptly posteriorly so as to form an angle at its point of junction with the blade portion, Tritoral area broadest somewhat in front of its middle, its greatest width contained from 1⅓ to nearly 3 times in the depth of outer face measured at middle of functional portion. Symphysis with three or four denticles, not always clearly shown. Margin immediately behind tritoral area, a compressed cutting edge, about half the length of the tritoral region. Inferior margin in front portion of mandible with a deep groove for attachment, extending forward to where the inferior margin blends into the front margin of the mandible.

Remarks.—This species is represented in the collection by the cotypes and by several other mandibles, one about the size of the cotypes, the others all smaller. Cotype 1, (fig. 29) shows the front half of the mandible in splendid preservation, lacking only the tip of the beak. Cotype 2, is less perfect, but shows almost the entire mandible including the blade or inserted portion. The functional portion in this element agrees closely with that of cotype 1. Among the smaller specimens, E 1966 shows the symphyseal denticles well.

This is the third species of *Dinomylostoma* to be described, the other two being, *Dinomylostoma beecheri* Eastman,[37] from the Portage of Mt. Morris, N. Y.; and *D. eastmani* Hussakof,[38] from the New Albany or

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[37] *Amer. Journ. Sci.*, 4 ser., xxi, 137, text- fig. 2, 1905; also a fuller discussion in *Bull. Mus. Comp. Zool.*, L, 23–29, pl. 1, figs. 4, 5; pl. 2, figs. 13, 14; Pls. 4, 5; text-figs. F–H, 1906.

[38] *Bull. Amer. Mus. Nat. Hist.*, xxxii, 245, pl. xlvii, fig. 7 and text-fig. 1 B, 1913.

"Genesee black shale," near Louisville, Ky. From these two, the present species is distinguished by the width of the tritoral area, and by the proportions of the mandible as a whole.

The following specimens seem to belong to this species. They are from the same formation and locality as the types and likewise were collected by W. L. Bryant.

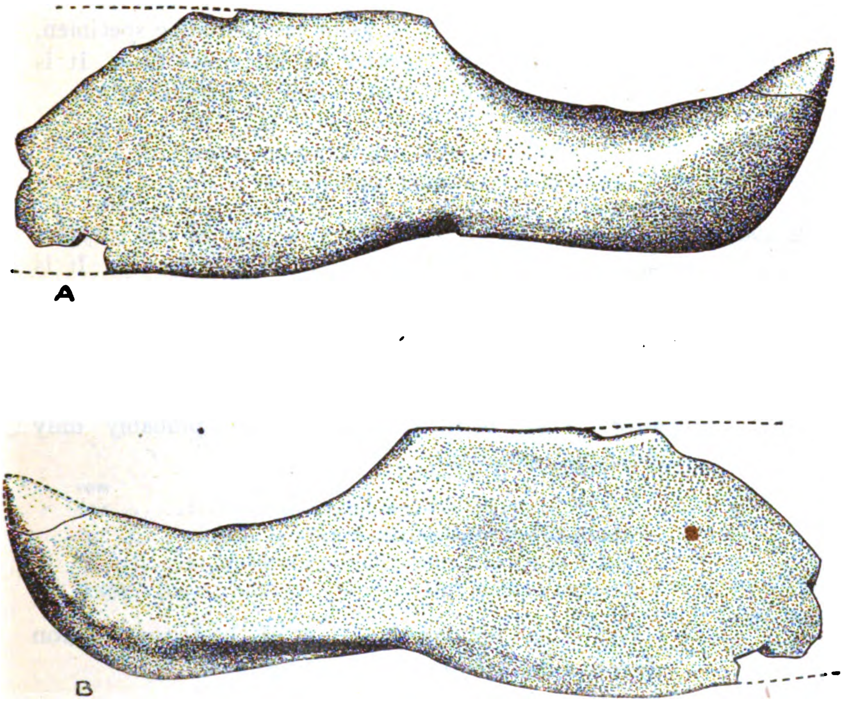

FIG. 29. *Dinomylostoma buffaloensis*, n. sp. RIGHT MANDIBLE, LACKING HINDER PART OF BLADE. NATURAL SIZE

A, outer view; *B*, inner. Cotype No. 1. E 1961.

E 1962 Front half of a small right mandible, which agrees closely with the cotypes. The tritoral area is much worn by use, appearing concave in profile view; and behind the tritoral area there is a short sectorial edge, beveled by wear on the outer face. This sectorial margin is straddled by three or four faint, line-like tritors, 2 or 3 mm. apart, each forming an oblique angle with the cutting margin.

	mm.
Length as far as preserved	62
Length of tritoral margin (concave portion)	40
Depth at middle of tritoral portion	12

E 1963 Front half of a small right mandible of about the same size as the preceding. It shows well the tritoral region and the beak, which is completely preserved. Behind the tritoral excavation there is, as in the preceding specimen, a compressed tritor, beveled on the outer face. It is straddled at intervals of 1 or 2 mm. by line-like tritors.

	mm.
Length of excavated portion of tritor	43
Length of element as far as preserved	61

E 1964 A right mandible of about the same size as the cotypes, lacking the posterior extremity (Pl. 23, fig. 1). It is embedded in matrix, and shown in outer view. It differs somewhat from the cotypes: the excavated portion of the tritoral area is shorter, and the outer margin of the tritoral area is a sharp line instead of being rounded outward. These features, however, are probably only individual variations.

	mm.
Length of element as far as preserved	122
Length of excavated portion of tritoral region	46
Depth at about middle of functional region	20
Greatest width of tritor	6

Behind the excavated portion of the tritoral region there is a short tritor 18 mm. in length.

E 1966 Front half of a small left mandible, showing well the excavated portion of the tritoral region and the beak (Pl. 24, fig. 4). In the symphyseal region there are three or four denticle-like protuberances, rather irregular in outline. The tritoral region behind the excavated portion is not preserved. Total length of element as far as preserved, 75 mm.; depth at about middle of functional region, 16.

E 1967 Front half of a left mandible, smaller than any of the preceding, and rather poorly preserved. The beak is missing, as is also the tritoral region behind the excavated portion of the tritoral margin.

E 1969 Beak of a right mandible about as large as the cotypes.

E 1968 A small left mandible (Pl. 24, fig. 5), which differs from all the preceding in the extreme shortness of the inserted portion, which thins out to a paper edge. This gives the element a peculiar appearance, as if it belonged to a different genus. However, as the inserted portion in mandibles of this species is very thin (as may be seen in the type specimens) and is frequently broken and further thinned by attrition, perhaps facilitated by the chemical disintegration of the superficial layer, it is reasonable to suppose that the extreme shortness and thinness of the blade in the present specimen is due to like causes. This conclusion is supported by the extreme similarity of the functional portion of the element to those described above. The element shows the excavated tritoral region, the beak (which is worn on the outer face), and the front portion of the compressed tritor behind the excavated tritoral portion. In the symphyseal region there are four or five small tritor-like protuberances, one above the other.

The groove for attachment, along the inferior margin of the element, is well shown. Length, 72 mm.; length of excavated portion of functional margin, 60.

E 2507 Front half of a right mandible. The symphyseal denticles six or eight in number, are worn down to their bases and the ridge upon which they stood is polished as by functional wear.

E 2508 Front half of a left mandible. The symphyseal denticles, four or five in number, are succeeded below by a polished ridge.

E 2509 Functional half of a right mandible. The specimen is thin and apparently water-worn.

E 2592 That this species occurs in the West River Shales, is shown by the impression of a large right mandible, lacking only the beak, in a thin limestone layer, collected by Mr. Bryant a few feet above the Genundewa limestone, at Windom, N. Y.

Dinomylostoma sp. [Juvenile]

(Pl. 23, fig. 2)

E 2042 A small left mandible on a piece of shale, shown in outer view. Length, 42 mm. This is the smallest *Dinomylostoma* mandible ever found, and probably represents a juvenile individual.

Rhinestreet shale (Portage); Sturgeon Point, on shore of Lake Erie, N. Y.; collected by Mr. F. K. Mixer.

Dinomylostoma ?

(Pl. 27, figs. 5, 6.—*Upper Dental Plates*)

E 1859 and **E 2398** There are two remarkable dental plates in the collection, from the Conodont bed at Eighteen Mile Creek, which differ from all other Arthrodire specimens known to us. They are apparently upper dental plates. From the presence of a large tubercle on the worn surface, (especially well shown in one of the specimens), and the fact that one of the lateral margins falls abruptly away from the wearing surface, somewhat as in a mylostomid dental plate, we are inclined to the view that the two elements are of the same kind, that is, upper dental plates of a mylostomid. And in fact, it is probable that they belong to one of the species of *Dinomylostoma* described above. The reasons for this view are chiefly these: (1) One may expect to find the upper dentition in the formation in which mandibles of the dinomylostomids are found, particularly so as the upper dental plates are compact and would stand an even better chance of preservation than the mandibles. (2) These elements, especially the one shown in Plate 27, figure 5, may be compared in a general way with a mylostomid upper dental plate. (3) Since in the mandible of *Dinomylostoma* the functional margin is excavated, one would expect that the apposing dentition would be convex, and this is the case with the present elements. So that, taken all in all, there is ground for believing that the two elements belong to the upper dentition of *Dinomylostoma*.

The reverse face of both specimens is covered with matrix which cannot be removed, so that the form of this face is unfortunately not to be seen. In the specimen shown in Pl. 27, fig. 6, one of the lateral margins is somewhat excavated, as if facetted for articulating with an adjoining element. This is precisely what one would expect in a *Dinomylostoma* upper dental plate.

Measurements:

E 1859—Length, 46 mm.; greatest height, 18.
E 2398—Length 42 mm.; height, 17

Conodont bed (Genesee); Eighteen Mile Creek, near N. Evans, Erie County, N. Y., collected by W. L. Bryant.

Aspidichthys notabilis Whiteaves

(Pls. 25, 26)

There are several plates in the collection, from the Conodont bed, that bear an ornamentation of large, low tubercles with faint stellations at their bases. These plates apparently belong to a single species. In their ornamentation they resemble most the isolated plates described by Whiteaves in 1892, from the Devonic of Manitoba, and named by him *Aspidichthys notabilis.*[39] The present specimens may, provisionally at least, be referred to the same species. The question, however, arises—Are these plates, and those described by Whiteaves, properly referable to the genus *Aspidichthys?* Whiteaves placed them in this genus with a question mark.

At the present time, three American Arthrodires are known that have an ornamentation of large tubercles, namely: *Trachosteus*, *Glyptaspis* and *Aspidichthys*. The specimens in hand must therefore be compared with these three genera.

As far as the genus *Trachosteus* is concerned, we have examined the type, which is preserved in the American Museum. The ornamentation of this genus consists of large tubercles somewhat comparable in size with those of the Conodont plates. But these tubercles are higher and more pointed, being in fact denticles rather than tubercles, and with very many more radiations at their bases and in the spaces between contiguous tubercles. In the Conodont bed specimens the

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[39] Whiteaves, J. F.: The fossils of the Devonian rocks of the islands, shores or immediate vicinity of Lakes Manitoba and Winnipegosis. *Contribs. to Can. Palæon.*, I, 354, pl. xlvii, 1892.

tubercles are all low, smooth and rounded, and may be described almost in the words applied by Whiteaves to those of the Manitoba specimens:

> The surface markings . . . consist of numerous small, smooth and rounded tubercles, which are unequal in size and irregular in their distribution, though the largest average 2 mm. in diameter at the base, and from 2 to 5 mm. in their distance apart at the summits. The greater part of the beveled or outer margin is smooth to the naked eye, but around its outer limits there are indications of short and irregular radiating grooves and ridges.[40]

It appears therefore, even on the evidence of the ornamentation alone, that the Conodont specimens do not belong to *Trachosteus*. There is, also, the further evidence from the shape of the plates. In *Trachosteus* the antero-ventrolateral is short and broad, and very different in form from the specimens in hand.

We have also compared the specimens with the genus *Glyptaspis*, using for comparison the type specimens which are in the Newberry collection in the American Museum. In *Glyptaspis* the antero-ventrolateral is fortunately known, so that we are able to compare plates of the same kind. But the denticles of the two forms are very different. In *Glyptaspis* they have a tendency to run into lines, and this is particularly well shown on the antero-ventrolateral. In the Conodont specimen of this plate, on the other hand, the denticles never run into lines, but always remain discrete. Furthermore, in *Glyptaspis* the antero-ventrolateral has a broad, smooth border on its outer or ornamented face, whereas in the Conodont antero-ventrolateral there is no such border, the tubercles running clear to the margin on one side, and on the other terminating in an irregularly delimited smooth area, not sharply defined from the ornamented portion. It seems, therefore, that the Conodont specimens cannot be placed in the genus *Glyptaspis*.

There then remains only the genus *Aspidichthys* of forms with tubercles comparable with those of the present specimens. In *Aspidichthys clavatus* Newberry, the tubercles are much larger than in either the present specimens or the Manitoban plates. However, their height, roundness, distribution, and the occurrence of smaller denticles amongst the larger ones, is in *Aspidichthys* very much as in the specimens in hand. The mere difference in size of the denticles would not exclude the present specimens from that genus, since it is known

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[40] Loc. cit., p. 355.

that there is considerable difference in the size and character of the tubercles among the species of one genus; in fact, one species may have tubercles and another not, as is seen in the genus *Dinichthys*. It therefore seems proper to refer the present specimens to *Aspidichthys*, merely extending the definition of this genus so as to include forms with denticles of the same kind, but of somewhat smaller size.

The following specimens are all from the Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, New York. Collected by W. L. Bryant.

E 1970 Right antero-ventrolateral lacking anterior portion (Pl. 25). The posterior tip is restored from a squeeze taken from the impression in the matrix. The plate as far as preserved, is 22 cm. in length, and 11 cm. in maximum width. The ornamentation consists of large, smooth, rounded tubercles, somewhat unequal in size and some of them slightly stellate at the base; a portion of the inner border of the plate is smooth, without denticles. The plate is practically uniform in thickness throughout and the under side is almost smooth, showing no striæ.

E 1971 An imperfect plate, probably a ventral, with its impression in matrix. Its ornamentation resembles that of the preceding specimen, except that in places the tubercles are somewhat more crowded. (Pl. 26, fig. 2.)

E 1972 Fragmentary plate.

E 2399 Impression of the front half of an antero-ventromedian and a plaster cast made from it (Pl. 26, fig. 1). This plate differs from all other antero-ventromedians yet described. Its characters are clearly brought out in the illustration. Along the front margin as well as on either side it has a broad flange for overlap by the other plates of the plastron. From the fact that it narrows but little posteriorly, it would appear to have been squared off more or less posteriorly, instead of ending in an acute point, as is the case in the species of *Dinichthys* in which the antero-ventromedian is a distinct plate. On the visceral surface the anterior margin is strengthened by a low ridge, and, running backward from this, in the median line, there is another low, rounded ridge very much as in *Dinichthys*,

This specimen was collected by Prof. C. J. Sarle.

E 1949 Two fragments, ornamented with large tubercles, apparently referable to this species.

Arthrodira, Gen. et sp. indet.

In addition to the Arthrodiran remains described in the preceding pages, there are a number of plates in the collection which apparently also belong to Arthrodires, but which are too imperfect for reference to particular genera. These are briefly described below, and the more interesting ones are figured. No doubt perfect specimens of most of them will in time be found and thus enable one to answer the tantalizing questions which they call forth.

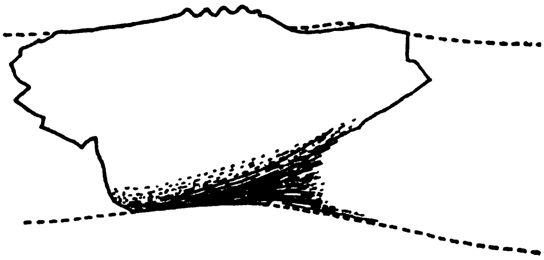

Fig. 30. Fragment of a Left Mandible of an Indeterminate Arthrodire; Outer View. Nat. Size. E 1945

a. Mandibles

There are three imperfect mandibles in the collection, representing one, and perhaps two, new genera of Arthrodires, but which are too imperfect to be named. For the present it seems advisable merely to illustrate and call attention to them. It is to be hoped that better material will soon be discovered which will make possible the defining of these interesting forms.

Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

E 1945 Fragment of a left mandible, consisting of the posterior half of the functional portion and the beginning of the blade portion (text-fig. 30). The oral margin is a cutting edge, rather blunt through use. At its posterior end are five low denticles, occupying a space of 12 mm. Behind the denticles the margin slopes down to meet the inserted portion of the mandible, producing a conspicuous "shoulder" in the region of these denticles.

E 1945a Fragment of a right mandible of about the same size, and showing about as much, as the preceding except that the cutting margin and the denticles are not so well preserved.

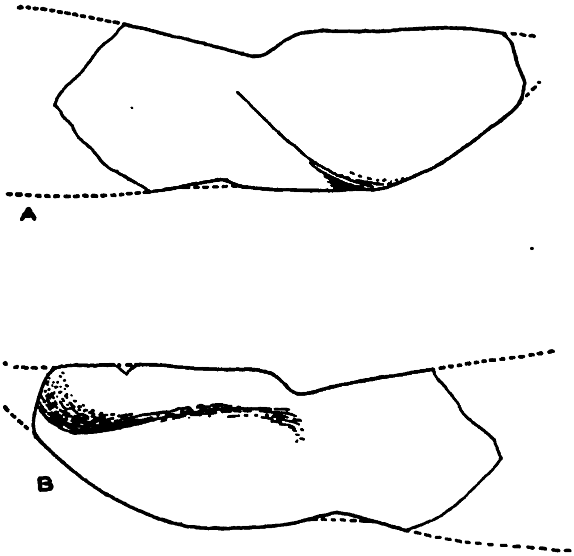

Fig. 31. Imperfect Mandible of an Indeterminate Arthrodire, Probably a New Genus. Nat. Size

A, outer view; *B*, inner. E 1934.

E 1934 Imperfect small mandible, lacking anterior extremity and the posterior part of the blade portion (fig. 31). The blade portion is demarcated from the functional portion, on the outer face, by a gradual change in level. The functional margin is a cutting edge with a "shoulder" at the point where it joins the inserted portion. The cutting edge is restored in the present condition of the specimen but was intact when the specimen was collected.

This mandable apparently represents a different genus from the two preceding. No doubt a perfect specimen of it will some day be discovered, and we may defer naming it until then. Its closest affinities seem to be with the genus *Hussakofia*.

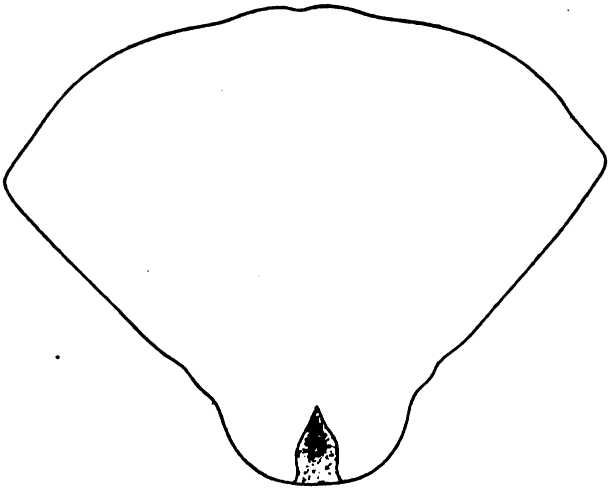

FIG. 32. RESTORED OUTLINE OF DORSOMEDIAN PLATE, × ABOUT ⅓. E 1892

b. Antero-superognathal

(Pl. 27, fig. 7)

E 1946 A small left antero-superognathal which differs from all other specimens of this element known to us. It consists of a single small but powerful cusp. There is no secondary cusp. The element is well shown in the figure in Plate 27. There is no doubt that it belongs to an Arthrodire, but we are unable definitely to assign it to *Dinichthys* or to any other genus.

Conodont bed; Eighteen Mile Creek, N. Y. Collected by W. L. Bryant.

c. Head and Body Plates

E 1867 Portion of a small lateral, or so-called "clavicular," plate.

Onondaga limestone (Mid Devonic); Cement Quarry, Buffalo, N. Y. Collected by W. L. Bryant.

E 1868 Fragmentary plate. Formation and locality same as preceding. W. L. Bryant, collector.

E 1892 One half of a dorsomedian plate, fractured along the median keel. The plate is massive and much waterworn, and probably belongs to an undescribed arthrodire. The half preserved measures 17.5 cm. in length and 12.5 cm. in greatest width. The keel apparently did not extend beyond the posterior extremity of the shield, at which point it is massive and deep (4 cm.), and apparently excavated. Figure 32 shows the restored outline, based on the half preserved.

Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by Prof. P. F. Piper.

E 2400 Impression in rock, with a fragment of the bone, of a small plate which tapers to a point. It is about 6 cm. long and 3.5 cm. at its widest part. It was keeled in the middle line, and suggests somewhat the dorsomedian of *Coccosteus*. The bone was very thin and its external surface seems to have been ornamented with broad lines running obliquely across the plate. It is impossible, of course, to determine the systematic position of this plate; it will probably turn out to be a new genus.

Conodont bed (Genesee), Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

E 1988 A small element tapering to a point; perhaps a lateral plate (Pl. 20, fig. 2).

Other data same as preceding.

E 2007 A small fragmentary plate apparently belonging to the orbital region of a cranial shield.

Other data same as preceding.

E 2043 A very small juvenile lateral, or "clavicular," of a Dinichthyid, in matrix; outer view. (Plate 28, figure 2.)

Rhinestreet shale (Portage); Sturgeon Point, N. Y. Collected by W. L. Bryant.

Genus **Acanthaspis** Newberry

This genus is known by isolated plates, usually with a spine attached to one side. They occur in the Devonic of both Europe and America—in America typically in the Mid Devonic limestone of Ohio, New York and Wisconsin.

There has been considerable discussion as to the affinities of these plates; but from the researches of Traquair,[41] and Smith Woodward,[42] it appears that they are the antero-ventrolaterals of a ventral armor somewhat similar to that of *Phlyctænaspis*, and hence that they represent an Arthrodire.

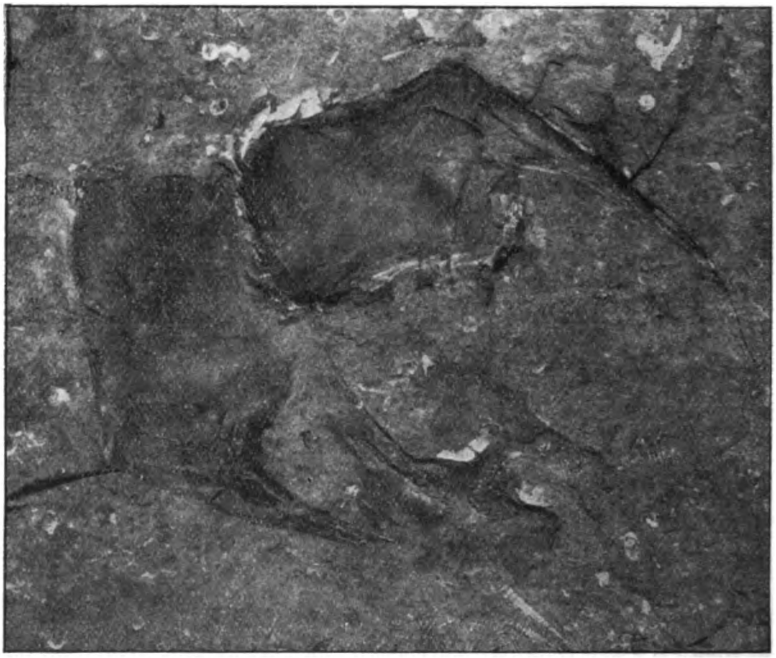

FIG. 33. *Acanthaspis armata* NEWBERRY. A PAIR OF ANTERO-VENTROLATERALS, IN INNER VIEW. × ½. E 1857

Recently Eastman[43] has advocated the view that they belong with

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[41] The Devonian fish fauna of Spitzbergen. *Ann. Mag. Nat. Hist.*, 1, 15, pls. i–iii, 1891.

[42] Further contribution to the knowledge of the Devonian fish fauna of Canada. *Geol. Magazine*, [3], ix, 481–485, pl. xiii, 1892.

On the Devonian fishes of Campbelltown and Scaumenac Bay in Canada, No. 2. *Geol. Magazine*, [3], x, 145–149, 1893.

[43] Devonian fishes of Iowa. *Ann. Report Iowa Geol. Survey*, xviii, 144, 1908.

the Ptyctodont tritors which are almost always found in the same rocks. This opinion, even if substantiated by the finding of *Acanthaspis* plates and Ptyctodont tritors in association, would not in our view militate against referring *Acanthaspis* to the Arthrodira, but be another link in the chain of evidence tending to prove that the Ptyctodonts are themselves Arthrodires, though with a specialized dentition.

In the Buffalo Museum there are two specimens of *Acanthaspis* that add somewhat to our knowledge of this form. One consists of two ventral plates, the right and left of one individual, on a block of limestone. Another is a plate with an attached spine in which the cross-section of the spine is clearly shown. This is elliptical, and proves that the spine was not as compressed as might be thought from its attachment to so thin a plate.

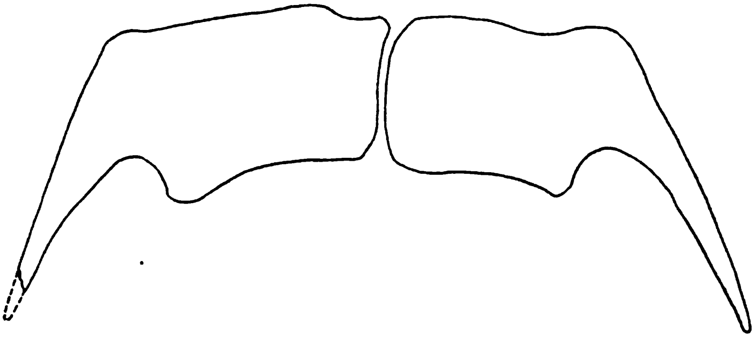

FIG. 34. *Acanthaspis armata* NEWBERRY. RESTORED OUTLINE OF SPECIMEN SHOWN IN FIGURE 33

Acanthaspis armata Newberry

E 1857 Block of limestone bearing right and left antero-ventrolaterals with their attached spines. (Text-figs. 33, 34.) There is also a fragmentary indeterminable plate on the same block. The specimens are shown in inner view; the suture between each plate and its attached spine cannot be made out. In one spot an impression shows the ornamentation of the outer face; this consists of the characteristic ornamentation of this species.

A restored outline showing the plates in natural relation to each other is given in figure 34.

Onondaga limestone (Mid Devonic); Williamsville, N. Y. Collected by Dr. Richard Rathbun.

E 2401 A rectangular plate with attached spine, on a piece of limestone; shown in outer view. The plate is mostly weathered away, but in places where it is preserved, it is seen to have an ornamentation of dots running into lines which are more or less parallel to one another and to the outer margin of the plate. An interesting feature of the specimen is the fact that the core of matrix of the proximal half of the spine seems to preserve the thickness of the spine in life (fig. 35). So far as we are aware, this is the first specimen of *Acanthaspis* to be found which clearly shows the section of the spine. This is elliptical and rather thicker than is generally supposed, the shorter diameter of the section being two-thirds the longer.

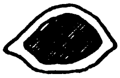

FIG. 35. *Acanthaspis armata* Newberry. CROSS-SECTION OF SPINE
The shaded area is the central cavity infiltrated with matrix; natural size. E 2401

The specimen agrees pretty closely with specimens of *Acanthaspis* from the Delaware limestone of Ohio, and although the ornamentation of the plate is rather more linear than is usual in these elements, still it seems to us referable to the typical species, *Acanthaspis armata*.

Onondaga limestone; Leroy, N. Y. Collected and presented by Prof. C. J. Sarle.

Acanthaspis sp.

E 2013 A detached spine (Pl. 28, fig. 4). It is of the usual form of the distal half of the spines of *Acanthaspis armata*, and somewhat triangular in cross-section. It bears a few scattered tubercles, and on the inner surface, parallel incised lines.

Conodont bed (Lower Genesee); Eighteen Mile Creek, North Evans, near Buffalo, N. Y. Collected by W. L. Bryant.

E 2024 Antero-ventrolateral lacking the lateral spine, shown in inner view (Pl. 30, fig. 2).

Genundewa limestone (Genesee); Eighteen Mile Creek, North Evans, near Buffalo, N. Y. Collected by W. L. Bryant.

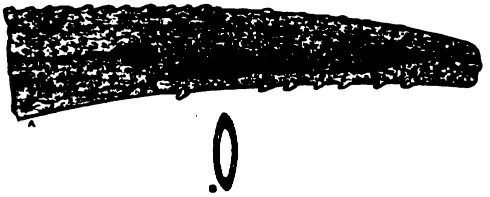

FIG. 36. *Acanthaspis* sp. DISTAL HALF OF A SPINE, × 2

A, side view; *B*, cross-section at about middle of spine. E 2029.

E 2029 Distal half of a small spine (fig. 36), apparently a lateral appendage of *Acanthaspis*, on a piece of shale. The ornamentation consists of tubercles, some of them elongated or tear-shaped and pointing downward. Length as far as preserved, 32 mm.; greatest width, 6; width near apex, 3.

Rhinestreet shale (Portage); Shore of Lake Erie, near Sturgeon Point. Collected by Dr. H. U. Williams.

INCERTÆ SEDIS

The genera and species following are known only by isolated armor plates whose relationships are at present unknown. Some of them—for instance, *Holonema*—seem to be Arthrodira, but concerning the others no positive statement can at present be made.

Eczematolepis fragilis (Newberry)[44]

(Pl. 29, fig. 2; Pl. 30, fig. 1)

This species has already been recorded from the Onondaga of western New York.[45] It is interesting to note that it, or a very closely

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[44] However undesirous we may be of using a name like *Eczematolepis*, the rule of priority leaves us no choice in the matter, since the earlier and more euphonious name, *Acantholepis*, is clearly preoccupied. See O. P. Hay: Bibl. and Catal. of the Fos. Vert. N. Amer., p. 332. *Bull.* 179, *U. S. Geol. Survey, 1902.*

[45] Eastman, C. R.: Devonic fishes of the N. Y. formations, p. 79. *N. Y. State Mus., Mem.* 10, 1907.

related form, occurs also in the Conodont bed at Eighteen Mile Creek, as evidenced by a specimen mentioned below.

E 1856 Fragmentary plate in matrix, showing the characteristic tuberculation of this species. (Pl. 29. fig. 2.)

Onondaga limestone (Mid. Devonic); Williamsville, N. Y. Collected by Dr. Richard Rathbun.

E 2014 Fragmentary plate, in matrix; shown in outer view (Pl. 30, fig. 1). It bears fine tuberculations and is on the whole comparable with the type species, *E. fragilis*.

Conodont bed (Lower Genesee); Eighteen Mile Creek, North Evans, near Buffalo, N. Y. Collected by W. L. Bryant.

Eczematolepis telleri (Eastman)

This species was described and illustrated in detail in a paper by Edgar E. Teller published in 1906.[46] Specimens are there figured showing a broad spine-like plate to which a second plate is attached, the two together suggesting somewhat the arrangement of an *Acanthaspis* plate and its spine. But there seems no ground for separating this form, from *Eczematolepis* as a distinct genus, *Phlyctænacanthus*, as was done by Eastman.[47] In fact these specimens from Wisconsin are so like those of *E. fragilis*, the type species, from Ohio, that there is barely ground even for specific separation from the latter form.

These plates have generally been found associated with dental elements of *Palæomylus*, and it is not improbable that they belong with this type of dentition.

E 1878 Plate in matrix, shown in outer view.

Hamilton (Mid. Devonic); Milwaukee, Wis. Collected and presented by Mr. Edgar E. Teller.

Holonema abbreviatum (Eastman)

(Pl. 31)

Glyptaspis abbreviata EASTMAN, New York State Mus., Mem. 10, p. 147, pl. 13. 1907.

In 1907 Eastman described a ventral plate from the basal strata of the Portage, which was ornamented with raised lines here and

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[46] *Bull. Wisconsin Nat. Hist. Soc.*, iv, 192, pl. iv.
[47] *Amer. Naturalist*, xxxii, 551, fig. 49. 1898.

there broken up into rows of dots. He referred it to the genus *Glyptaspis* of Newberry, under the specific name *abbreviata*.

Apart from this species *Glyptaspis* is known only by the type species *G. verrucosa* Newberry. A cast of Eastman's specimen is in the American Museum and we have compared it carefully with Newberry's types of *G. verrucosa* which are also in the American Museum; and we have come to the conclusion that the *abbreviata* plate does not belong in the genus *Glyptaspis*. G. *verrucosa* is ornamented with large tubercles, closely rounded, and arranged in rows, whereas *G. abbreviata* is ornamented with thread-like lines and dots which are much finer than in the former species. Moreover, the *abbreviatum* plate seems too short and broad to belong with such plates as those named *G. verrucosa*; they indicate an animal of very different proportions. The type of *G. abbreviata* belongs properly in the genus *Holonema* of Newberry, in which it may stand as a distinct species distinguished from the other species known, by the width of the spaces separating the lines of ornamentation and by the breaking up of these lines into discrete dots, even more so than in *Holonema rugosum*.

The species was previously known from the Portage of western New York and from the Genesee of Kentucky-Indiana. Three specimens in the Buffalo Museum establish its presence in the Conodont bed (basal Genesee), and in the limestone layer above the Genundewa, and thus prove it to range in western New York from the base of the Genesee up into at least the lower portion of the Portage.

E 2009 Imperfect plate, ornamented with nearly straight, parallel beaded lines.

Conodont bed (Lower Genesee); Eighteen Mile Creek, North Evans, near Buffalo, N. Y. Collected by W. L. Bryant.

E 2444 Lateral or ventral plate with the characteristic ornamentation of this species, with straight margins on three sides. It measures 11.5 by 9 cm.

Other data same as preceding.

E 2025 A flat, subrectangular plate apparently belonging to the ventral armor (Pl. 31). It is almost complete, and its ornamentation agrees closely with that of the type specimen of *Glyptaspis abbreviata* figured by Eastman. At the upper and lower margins of the plate, the ornamentation consists almost entirely of raised dots; these coalesce more and more toward the center of the plate tending to fuse into irregular and tortuous thread-lines trending in a general way toward the center of the plate. The plate is very thin, not more than one-eighth of an inch in thickness. Length 110 mm.; greatest width 65.

From the limestone band in the West River shale (Genesee), a few feet above the Genundewa Limestone. Eighteen Mile Creek, North Evans, near Buffalo, N. Y. Collected by W. L. Bryant.

Holonema rugosum (Claypole)

(Pl. 32, fig. 1)

E 2513 Cast of a plate 12 by 13 cm. It is of great interest for showing on the outer, ornamented face several tooth marks apparently inflicted by a contemporary animal, probably a dinichthyid.

Original in private collection of Mr. Edgar E. Teller of Buffalo, N. Y., to whom we are indebted for the privilege of taking casts not only of this but of a number of other specimens.

Hydraulic cement rocks (Mid. Devonic); Milwaukee, Wis.

The fragmentary plates figured by C. K. Swartz in his recent work on the middle and upper Devonian of Maryland, under the name *Glyptaspis eastmani* (*Maryland Geol. Surv.: Middle and Upper Devonian*, p. 700, pl. 73, figs. 1–3, 1913), seem to us to belong in this genus and even perhaps in this species, which apparently had a wide geographical distribution.

Holonema sp.

(Pl. 33, fig. 2)

E 2512 Cast of a fragmentary plate remarkable for its thickness (1 cm.). It is apparently a fragment of a much larger plate. It is ornamented on the outer face with thread-like lines which anastomose in places into a reticulated network, on the whole more suggestive of *Holonema* than of any other genus.

Original in collection of Mr. Edgar E. Teller.

Hydraulic cement rocks (Mid. Devonic); Milwaukee, Wisconsin.

Oëstophorus lilleyi (Newberry)

(Pl. 33, fig. 1)

Sphenophorus lilleyi NEWBERRY, Paleozoic Fishes N. Amer., p. 92, 1889.

In his *Paleozoic Fishes of North America*, Newberry described (p. 92, Pl. xx, fig. 15) an imperfect plate from the Chemung of Pennsylvania, remarkable for bearing an ornamentation of arrowhead-shaped tubercles. He regarded it as a clavicle probably belonging to a crossopterygian. Since that time, other fragmentary plates with a similar ornamentation have been found, notably in the Hamilton of Wisconsin, but none perfect enough to throw light on their taxonomic position. And it is true now as was said by Newberry that, "until some other portions of the fish shall be discovered, it will be impossible to speak positively in regard to its relations."

In the collection of Mr. Edgar E. Teller of Buffalo, there is one of these plates, from the Hamilton of Milwaukee, which seems to bear an attached spine as in *Acanthaspis*, but as neither the plate nor the spine are very perfect, we hesitate to draw any conclusion from the specimen as to the relationship of the genus.

Fragmentary plates bearing the same style of ornamentation, and probably referable to the same species, occur in the Conodont bed at Eighteen Mile Creek. One such plate in the Buffalo Museum is illustrated in Plate 33, figure 1.

E 1898 Fragmentary plate showing the characteristic arrowhead-like ornamentation, 8 by 5 cm.

Hamilton limestone (Mid. Devonic); Milwaukee, Wis. Collected by Mr. Edgar E. Teller.

E 2012 Small fragmentary plate showing the arrowhead-like ornamentation characteristic of this genus (Pl. 33, fig. 1).

Conodont bed, (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Dermal Plates—Gen. and sp. indet.

(Text-fig. 37)

Two fragments of plates in the collection, found in the Conodont bed, at Eighteen Mile Creek, differ from all other ornamented plates hitherto described and probably represent a new genus. They are flat, 2 to 4 mm. in thickness, with one face perfectly smooth, and the other ornamented with parallel, low, rounded ridges which gradually diminish in diameter toward one side of the plate. Along one edge, which is perfect, the smooth face of the plate (in both specimens) is beveled to a knife edge, the beveled margin being 4 mm. in width. The ornamented face, on the other hand, shows no beveling, the ridges continuing clear up to the edge. The ridges make an angle of about 60° with this natural edge.

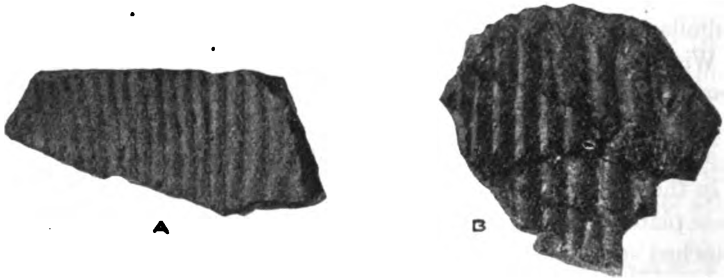

FIG. 37. FRAGMENTS REPRESENTING AN UNDISCOVERED GENUS, PROBABLY ARTHRODIRAN. NATURAL SIZE

A, fragment with narrow ridges; E 2440. B, fragment with coarser ridges E 2439.

These fragments clearly indicate a form different from any hitherto described. They may be compared only with *Holonema* plates, although in the latter genus the ridges are very much finer and usually broken in places into dots. The fragments appear so peculiar that we have even doubted whether they belong to fishes, but micro-sections of them clearly show bone cells.

It would, of course, be premature to name this form until at least one complete plate is found.

E 2439 A fragment 3 cm. in length (fig. 37B), bearing 8 low ridges on the ornamented face. The broadest ridge is 4 mm. wide, the narrowest about 2.

Conodont bed, (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

E 2440 A fragment similar to the preceding, 3.5 cm. in length (fig. 37 A), with narrower ridges and the spaces between them somewhat wider than in the preceding (one-third to one-half the width of the ridges).

Formation and locality same as preceding.

CYCLIÆ

Palæospondylus gunni Traquair

E 2441 A specimen showing the head and vertebral column in great perfection, but lacking detail in caudal fin. On the same slab is a poor specimen of *Mesacanthus peachi* (Egerton).

Middle Old Red Sandstone; Achanarras, Caithness, Scotland.

PTYCTODONTIDÆ

The family Ptyctodontidæ is known only by dental plates and isolated tritors. Associated with them are plates of various genera—e. g., *Acanthaspis*, *Eczematolepis*—and the suggestion has been made that these are the body-plates of the fishes to which these dental plates belonged. However, conclusive proof of this is not yet at hand, and for the time being we must continue to refer to the body-plates and the dental elements under separate names.

There are three genera of the Ptyctodontidæ: (1) *Ptyctodus*, with the entire, or almost entire, oral margin formed into a grinding tritor; (2) *Rhynchodus*, with oral margin a cutting blade; (3) *Palæomylus*, with a grinding tritor, but the element is much larger and differently formed from that of *Ptyctodus*. Of these genera, the first and third are confined to the Devonic, while the second ranges into the Carbonic.

The genus *Rhamphodus*, described by Jaekel from the Eifel Devonic is apparently identical with *Rhynchodus*, as was pointed out by Eastman.[48]

In addition to these there is a new form described as a new genus on a subsequent page of this catalog.

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[48] "Devonian fishes of Iowa." *Ann. Rept. Iowa Geol. Survey*, xviii, 127–129, 1908.

Genus **Ptyctodus** Pander

The Conodont Bed at Eighteen Mile Creek has yielded a wonderful series of ptyctodont dental plates and tritors,—without question the largest number of perfect specimens ever obtained from any formation, or, in fact, from all other formations put together. Three species are represented here—*Ptyctodus calceolus*, the typical and most widely distributed species, which ranges through the Middle and Upper Devonic; *P. compressus*, a species hitherto known only by a few imperfect elements from the Upper Devonic of Iowa; and *P. howlandi*, a splendid, large species described here for the first time.

Ptycotdus calceolus Newberry & Worthen

(Pl. 34; Pl. 36, figs. 1, 2, 10; Pl. 37, fig. 9)

This species is represented in the Buffalo Museum by two series of dental plates and tritors—one from the Hamilton of Milwaukee, and a second and larger series from the Conodont bed at Eighteen Mile Creek.

a. Specimens from the Hamilton limestone (Mid. Devonic); Milwaukee, Wis. Collected and donated by Mr. Edgar E. Teller.

E 1884 Right lower dental plate (Pl. 34, figs. 1 and 3).
This specimen is of unusual size, being nearly 6 cm. in length. It apparently belonged to an old individual; the triturating surface is worn down below the level of the lateral faces of the plate.

E 1885 An isolated tritor.

E 1886 An isolated tritor.

E 1887 An isolated tritor.

E 1888 Left upper dental plate.

E 1889 Imperfect right lower dental plate.

b. Specimens from the Conodont Bed (Lower Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Owing to the refractory character of the Conodont bed limestone, it is very difficult to extricate the tritors from the matrix; the specimens are usually broken and in most instances the thin side walls are lost. These specimens agree well with those from the Hamilton of Milwaukee, from which they are specifically indistinguishable.

E 1913 Three small upper dental plates in splendid preservation (Pl. 36, figs. 1, 2; Pl. 37, fig. 9). They show the low beak, the entire tritor and the bevelled cutting margin. They are relatively shorter and broader than the upper dental plates of *P. compressus*, and the region back of the tritor falls away uniformly all around; i.e., the inner and outer faces do not meet in a sharp edge behind the tritor as in *P. compressus*. The smallest of the three elements is 22 mm. in length (including 1 mm. allowed for missing posterior extremity). The next larger element is 37 mm. in length; height of beak (its lower margin is completely preserved), 10 mm. (including 1 mm. allowed for missing tip); max. width of tritor, 4.5 mm. The tritor shows clearly the rows of punctæ. The largest element is 40 mm. in length; height of beak, 9; max. width of tritor 4. The tritor is much worn and the rows of punctæ while present are scarcely seen.

E 2409 Two imperfect tritors of dental plates much larger than the preceding. They clearly belong to *P. calceolus* as shown by their width, which is much greater than in *P. compressus*, and, in one of them at least, the absence of the ridge behind the tritor. The larger of the two specimens shows the rows of punctæ, although they are obliterated in places through wear. In the other specimen—the posterior half of a tritor—the punctæ have been almost entirely obliterated.

E 2431 A left upper dental plate shown, natural size, in Plate 36, figure 10. The beak is rounded off, and just behind it is a bevelled area produced by the play against it of the left lower beak.

Ptyctodus compresses Eastman

(Pl. 36, figs. 3–9, 11, 12; Pl. 37, figs. 1–8, 10–13)

This species is represented in the collection by over three dozen specimens, collected at various times by Mr. Bryant, from the Conodont bed, at Eighteen Mile Creek. It is the finest series of ptyctodont plates of one species ever assembled, some of the specimens being exquisitely preserved and showing all the details of structure.

E 1911 A rather large, perfect right lower dental plate, (Pl. 37, fig. 12) partly embedded in limestone; in inner view. Length 46 mm.; height at beak, 14; max. width of tritor, 6. The rows of punctæ are well shown, as is also the compressed edge back of the tritor.

E 1912 A large, much worn, left lower dental plate (Pl. 36, fig. 9). This is the largest specimen of this species ever found. It is 68 mm. in length (including in this 5 mm. allowed for missing posterior extremity). Max. width of tritor, 8 mm. The tritor is much worn, posteriorly excavated so that the region back of the tritor appears to rise upward. The linear arrangment of the punctæ is entirely obliterated.

E 1914 Five right lower dental plates. One, in inner view (Pl. 37, fig. 6), is 43 mm. in length (including in this 3 mm. allowed for missing posterior extremity). It is one of the most perfect dental plates ever found. It shows well the spiniferous process below the symphyseal region. The beak is pointed, and the cutting edge following it, as well as the tritor, are well preserved. It shows the inferior margin of the inner side, which is very rarely preserved. The others are shown in Plate 36, figures 3, 8, 12; Plate 37, fig. 4.

E 1914-A Two left lower dental plates (Pl. 37, figs. 3 and 5), one of them embedded with its lower margin in matrix.

E 1916 Two rather small right upper dental plates. We figure one of these in Plate 36, figure 5.

E 1917 Three left upper dental plates, one of them in matrix (Pl. 36, fig. 6; Pl. 37, fig. 2).

E 1921 A very small lower dental plate. Despite its small size, it shows all the characters of the species—beak, cutting margin, narrow tritor and compressed edge behind tritor. Total length, 15 mm.

E 1922–3 (1) A right lower dental plate, lacking only the tip of the beak; (2) the front half of a left dental plate.

E 1924 Imperfect left lower dental plate.

E 1925 Minute right lower dental plate.

E 1931 Imperfect lower dental plate, in limestone.

E 2404 A right lower dental plate showing well-preserved oral margin (Pl. 37, fig. 11).

E 2406 Two rather small upper dental plates. One of them, of the right side, is figured (Pl. 37, fig. 1).

E 2407 A rather large, worn lower dental plate, lacking the hinder third.

E 2408 Two left lower dental plates (Pl. 37, figs. 10 and 13). The larger and better preserved one of the two (fig. 10), is the next largest element to No. E 1912 in the collection. It shows well the spiniferous process, below the symphyseal region both in outer and inner view. Length 58 mm. (including 3 mm. allowed for missing posterior extremity). Height at beak, 15; max. width of tritor, 5. The tritor shows the rows of punctæ, although they are a good deal worn and in the front half of the tritor are completely obliterated.

E 2410 Right lower dental plate (Pl. 36, fig. 4). The tritor is very narrow and the cutting edge in front of it is but little developed. The beak is sharply pointed. The ridge behind the tritor is well shown.

E 2411 Eight small dental plates, three of them among the smallest ever collected. The smallest is only 11 mm. in length; another, lacking the posterior end, is 14 mm. in length, when complete must have been about 18 mm.

E 2432 Four right lower dental plates ranging from 21 to 43 mm. in length. Two of them (Pl. 36, fig. 7; Pl. 37, fig. 8), show the inner face better preserved than in any other specimen. This is very deep, giving the plate in inner view a somewhat semilunar appearance.

E 2433 A large left lower dental plate (Pl. 37, fig. 7).

That this species occurs in rock of Tully age, is evidenced by the following:

E 2402 Upper dental plate, 17 mm. in length.
Pyrite layer of the Tully horizon, Cazenovia Creek, Springbrook, N. Y. Collected by W. L. Bryant.

Ptyctodus compressus? Eastman

E 1892 An imperfect dental plate.
Hamilton limestone (Mid. Devonic); Milwaukee, Wis. Collected by Mr. Edgar E. Teller.

E 1893 An imperfect dental plate.
Formation and locality same as preceding.

Ptyctodus howlandi, n. sp.

(Pl. 38; text-fig. 38)

E 1919 *Type.*—Left lower dental plate. Length 102 mm.; depth at center, 22.

Horizon and Locality.—Conodont Bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Dental plate elongated, shallow (in outer view), its hinder third rising gently toward the posterior extremity. Depth at middle of element contained 4¾ times in its length. Oral margin consisting of a prominent "beak," followed by a cutting edge extending to end of second third of the oral margin, at which point there is a depression formed by the opposing upper tritor; then, in last third of element, a broad tritoral area, which rises from inner face outward so as to form with this face a sharp edge especially pronounced in hindermost portion of the tritor. Tritor covered with punctæ, which in its middle portion are arranged into more or less longitudinal rows, while in the posterior portion, where they are extremely numerous, they are arranged into rough lamellæ. Side walls covered with similar polished rugosities and irregular punctæ so characteristic that even the smallest fragment of this species can be easily identified. Symphyseal region prolonged downward in a short spiniferous process (this is not shown in the type, but is seen in a paratype—E 2426).

Remarks.—This species is represented in the collection by the type, a specimen referred to above as the paratype, and a number of other dental plates more or less perfectly preserved. The type and paratype are practically perfect. They indicate a well-marked species readily distinguished from all others. The special peculiarity of this species lies in the fact that the tritoral region is divided by a depression formed by the opposing upper tritor into two portions: an anterior portion forming a sectorial edge just behind the beak and thickening a little posteriorward; and a posterior portion—a tritor remarkable for the fact that its outer face is a sharp edge, so that the dental plate in this region was at once sectorial and tritorial in function.

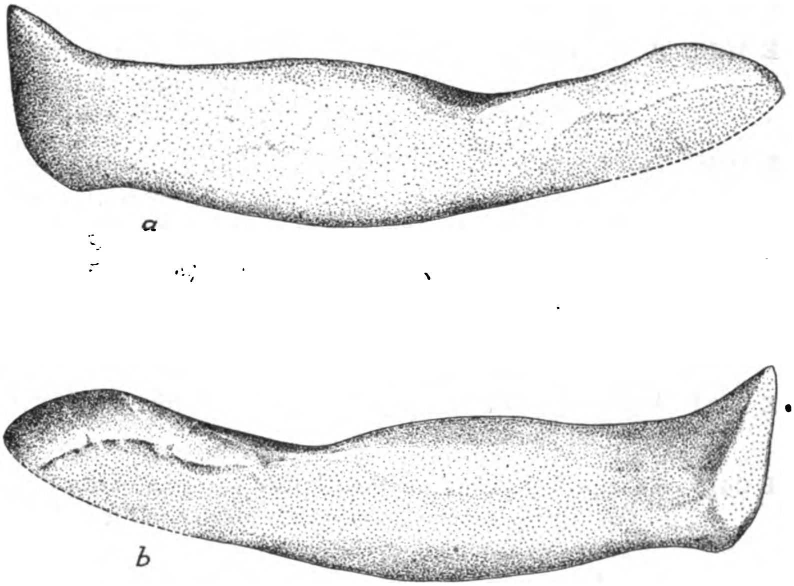

FIG. 38. *Ptyclodus howlandi*, n. sp. LEFT LOWER DENTAL PLATE IN OUTER (*a*), AND INNER (*b*), VIEWS. TYPE; NATURAL SIZE. E. 1919

P. howlandi is at once distinguished from the four or five other known species, by its size and form, its pronounced beak associated with relative shallowness in outer view, and by the remarkable knife-edge formed by the outer margin of the posterior tritor.

The species is named for Mr. Henry R. Howland, of the Buffalo Society of Natural Sciences, in appreciation of his interest in the development of the fish collection in the Buffalo Museum, and of the encouragement he has given us in the preparation of this catalog.

The following specimens are all from the type locality and were collected at various times during the past four years by Mr. Bryant.

E 1920 Right lower dental plate, perfect as far back as the hinder portion of the tritor. The beak is rather low and worn, and the cutting edge following it is also much worn.

E 1926 Two fragments of dental plates exhibiting a portion of a narrow tritor joining a sharp edge. The tritor is much worn so that the line joining it with the cutting edge rises almost perpendicularly (Pl. 40, figs. 2, 3). No complete specimens of this type of dental plate have yet been collected, and it is possible that when one is found, it may turn out to be a distinct species.

E 2412 A number of fragmentary tritors and sectorial margins of dental plates of various sizes.

E 2413 An imperfect right lower dental plate somewhat larger than the type specimen. It shows the greater portion of the tritor and about half of the pre-tritoral region.

E 2414 Anterior half of an upper dental plate. The beak is low and rounded, and the cutting edge behind it very sharp and unworn (perhaps a young specimen). Only the front portion of the tritor is present. Length from anterior margin to end of cutting edge, 33 mm.

E 2415 Two imperfect dental plates of specimens about as large as the type. They show the greater portion of the anterior cutting edge and about half of the tritor behind it.

E 2416 Tritor of a rather large dental plate, larger than the preceding. It narrows anterior-ward and lacks only about 0.5 cm. of the front end.

E 2421 Complete right lower dental plate of a mature individual (Pl. 38, fig. 6).

E 2425 Three beaks of lower dental plates, about as large as the type specimen.

E 2426 A left lower dental plate somewhat smaller than the type (Pl. 38, fig. 2). It is one of the most perfect specimens found, and shows well the characters of the species. Total length, 86 mm. (including 3 mm. allowed for missing posterior extremity); depth at about middle of element, 21 mm.

E 2427 An incomplete right lower dental plate of an older specimen than the preceding. That it is older is shown by the blunt, worn-down condition of the cutting edge behind the beak, which has the appearance of a tritor rather than a cutting edge. Only the front region of the tritor proper is preserved.

E 2429 An imperfect left lower dental plate on limestone, shown in inner view. The beak as well as the greater portion of the functional margin are lacking, so that it is not absolutely certain that the specimen belongs to this species; it resembles this species, however, more than any other.

E 2434 Fragmentary dental plate showing the greater portion of the pre-tritoral cutting edge and the front half of the tritor of a rather young specimen.

E 2437 Well-preserved beak of a large lower dental plate.

The following specimens perhaps also belong to *Ptycodus howlandi*, but this cannot be asserted positively. They are also from the Conodont Bed at Eighteen Mile Creek.

E 2456 Three anterior extremities of upper dental plates of different sizes.

Ptyctodus ferox Eastman

Specimens collected by Mr. E. E. Teller from the Hydraulic Limestone, at Milwaukee, Wis.

E 1890 Complete lower dental plate, somewhat crushed; in matrix. Length, 13 cm.; greatest depth, 6.

E 2442 Cast of a complete left lower dental plate. Length, 12 cm.; depth at symphysis, 7. Original in Mr. Teller's private collection.

E 2443 Cast of a complete left upper dental plate 15 cm. in length. The upper dental plates are much more sigmoidally flexed than the lower. Original in Mr. Teller's private collection.

Rhynchodus excavatus Newberry

E 1879 Left lower dental plate.

Hamilton limestone (Mid. Devonic); Milwaukee, Wis. Collected by Mr. E. E. Teller.

E 1880 Right lower dental plate. Same as preceding.

E 1881 Right lower dental plate. Same as preceding.

Rhynchodus telleri, n. sp.

(Text-fig. 39)

E 2436 *Cotypes.* (1) A dental plate lacking the beak, embedded in matrix and shown in outer view. The functional margin is entirely free from matrix. Length 67 mm.; depth at about middle, 14.

E 1927 (2) An incomplete dental plate, free of matrix, showing the greater portion of the cutting edge.

Formation and Locality.—Conodont bed (Genesee), Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Dental plate relatively slender, its maximum depth about ¼ the total length. Functional margin a sharp cutting edge with a well-pronounced beak; not perfectly straight, but with a gentle elevation at a point somewhat in front of the middle of the element, from which it falls away gently on either side. Below the beak a spiniferous process.

Remarks.—This species is readily distinguished by the proportion of length to depth of the element; by the gentle undulation of the cutting margin and by the strong beak.

We take pleasure in naming this species for Mr. Edgar E. Teller, of Buffalo, N. Y., in appreciation of his valuable work in collecting and studying the Devonic fishes, especially those of the Hamilton of Wisconsin.

The following specimen probably also belongs to this species:

FIG. 39. *Rhynchodus telleri.* n. sp. DENTAL PLATE, NATURAL SIZE
Cotype No. 1. E. 2436

E 2435 A dental plate in matrix, shown in inner view. The beak is lacking, but the region below it is well shown. This forms a ridge in the region of the symphysis. The anterior two-thirds of the cutting margin is also lacking, but from the posterior third, which is well-preserved, it is seen that the cutting edge extended to the extreme end of the element, as it does also in Cotype No. 1. Total length, 76 mm. (including 2 mm. allowed for missing portion of beak); depth at hinder third (which is perfectly preserved), 13.

Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Rhynchodus ornatus, n. sp.

(Pl. 39, figs. 1, 1a, 2)

E 1950 *Cotypes.* Two left lower dental plates, lacking the posterior extremities. (1) Length, 50 mm.; height (at middle) 20. (Pl. 39, figs. 1, 1a).

E 1950(a) (2) Length, 45 mm.; height 20 (Pl. 39, fig. 2).

Formation and Locality.—Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Dental plate subquadrangular, the upper margin more or less parallel to the lower; symphyseal margin making an angle of about 135° with the inferior margin. Oral margin a cutting blade bevelled by wear on outer face, with a small beak-like projection at its anterior extremity. Symphyseal face bent inward at right angles to the outer face and forming a smooth symphyseal facet about 3 mm. in width, extending downward for about two-thirds the height of the plate, and terminating on its innermost margin in two protuberances, of which the lower one is the larger. Cross-section of dental plate thickest at about one-third its height from the bottom, where it measures 5 mm., and gradually thinning out towards the cutting edge; inner face strengthened by very faint ridges. Outer as well as inner faces of plate ornamented with fine lines running parallel to the long axis; these lines connected with one another at frequent intervals and appearing under the glass as a fine reticulated network; this ornamentation extends almost to the cutting edge of the plate where, however, it is mostly obliterated through wear. In one of the two cotypes, the ornamentation can be clearly seen curving around the front margin of the plate below the symphyseal area.

Remarks.—These two dental plates indicate a highly differentiated species of *Rhynchodus*. This is easily distinguished from all other species by the remarkable ornamentation and the peculiar form. In neither specimen is there any indication of a spiniferous process below the front of the plate.

The symphyseal facet is unusual and worthy of comment. It is bent in at right angles to the outer face of the plate and formed as in *Coccosteus*, except that the five or six symphyseal denticles of the latter, are represented by only two low denticle-like protuberances. It cannot be made out whether the symphyseal edges wer eunited, or were free and more or less functional. They do not show any lines of wear.

E 1947 Two dental plates apparently referable to *Rhynchodus ornatus*, remarkable for the ornamental tubercles on the outer face (Pl. 39, figs. 3, 3a, 4, 4a).

E 1947a Conodont Bed (Lower Genesee); Eighteen Mile Creek, Erie County, N. Y. Collected by W. L. Bryant.

Palæomylus greenei (Newberry)

(Text-fig. 40)

E 1891 Greater portion of a right lower dental plate. The beak of the element is restored in plaster so that the plate looks complete. Length 17.5 cm.; greatest depth, about 9.
Hamilton, (Mid. Devonic); Milwaukee, Wis. Collected by Mr. E. E. Teller.

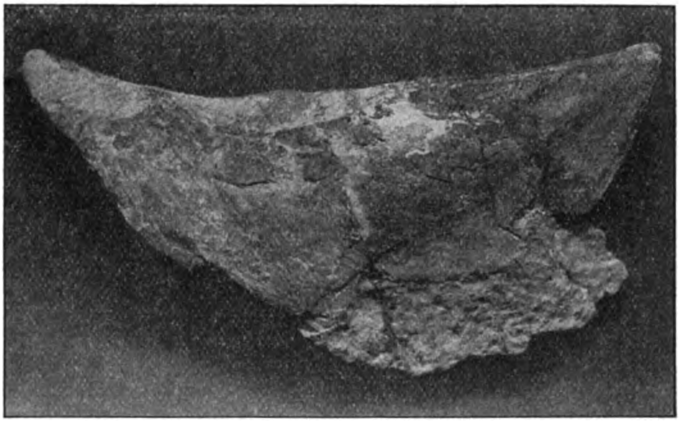

FIG. 40. *Palæomylus greenei* (Newberry). RIGHT LOWER DENTAL PLATE, × ½ Beak and posterior extremity are partially restored. E. 1891

Palæomylus lunaformis, n. sp.

(Pl. 40, fig. 6, and text-figs. 41–42)

E 1928 *Type.* A lower dental plate on a block of limestone. The front half of the specimen is represented only by the impression. Length (slightly restored posteriorly), 84 mm.; depth at about middle, 44.

Formation and Locality.—Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

A species of about the size of *Palæomylus frangens*, gracefully sublunar in outline, with the anterior extremity turned up into a beak.

Front half of functional margin, in profile view, gently excavated; hinder half almost straight and rising gently to the posterior extremity. Posterior part of tritor narrow. [Front portion not preserved.]

Remarks.—This gracefully formed dental plate is readily distinguished from the other three species of *Palæomylus* by its outline. Its front margin rises more abruptly upward than in the other species, and the plate as a whole, disregarding the posterior angle, is relatively deeper in proportion to its length. The difference in outline between this plate and the other three species is clearly brought out in fig. 42,

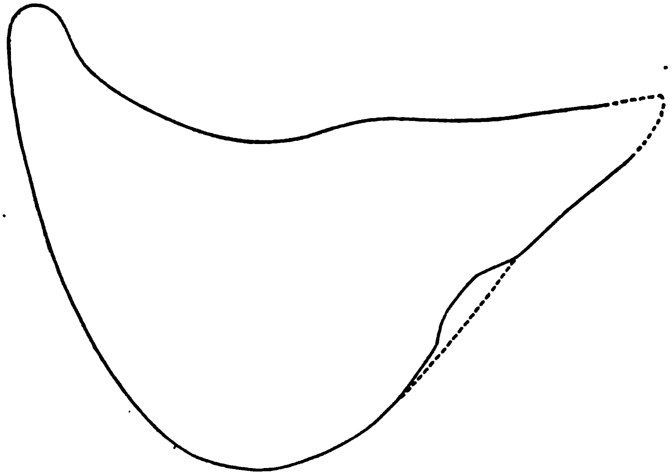

FIG. 41. *Palæomylus lunaformis*, n. sp. OUTLINE OF TYPE DENTAL PLATE, SHOWN IN PLATE 40, FIGURE 6. NATURAL SIZE. E. 1928

The following specimen which is larger than the type, perhaps also belongs to this species.

E 2445 A large imperfect dental plate measuring 13.5 cm. in length as far as preserved. It shows the greater portion of the tritoral area and a part of the outer and inner walls of the element. The tritor is 1.5 cm. at its widest point, and narrows anterior-ward to a sharp edge. Its surface is worn, but it shows no linear arrangement of punctæ.

Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

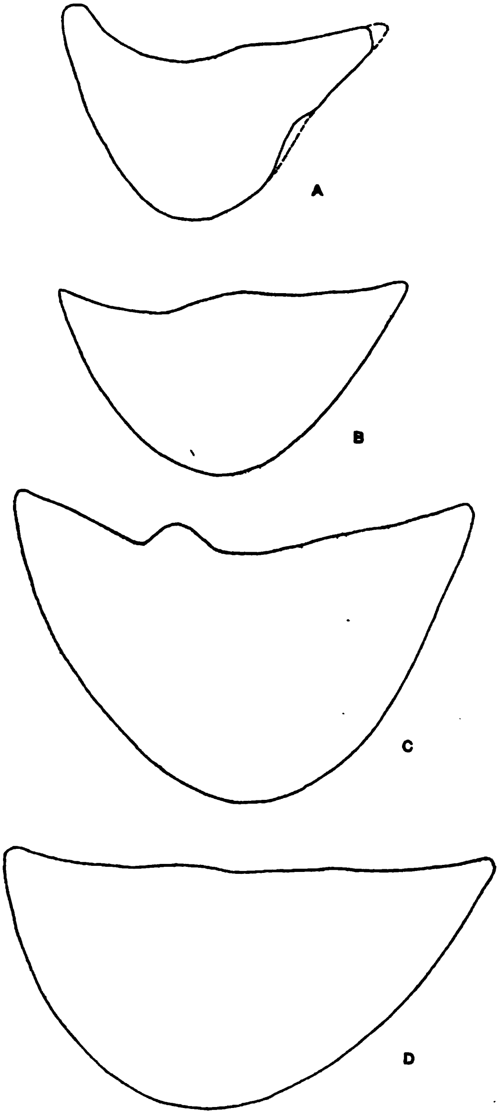

Fig. 42. Diagram Key to the Known Species of *Palæomylus*, Illustrating Also Their Relative Sizes

A, *P. lunaformis*, n. sp.; **B,** *P. crassus*; **C,** *P. frangens*; **D,** *P. greenei.*

Palæomylus sp.

(Pl. 41)

Besides *Palæomylus lunaformis* there is a species resembling *P. greenei* in the Conodont bed at Eighteen Mile Creek; but none of the specimens of it so far obtained is perfect enough to show whether it is this species or a distinct form. It is extremely Chimæroid-like in appearance, the dental plates in oral view being almost exactly like those of *Edaphodon* from the Cretaceous of New Jersey. The anterior extremity rises into a short beak, and the oral margin has two large tritors, an anterior one situated close to the inner margin, and a posterior one near the outer margin. The symphyseal area is very broad, extending inward as far as the first tritor, from which point it descends in a sharp line.

It is to be hoped that complete elements of this interesting species may be found, for they will, no doubt, add considerably to our present knowledge of the genus *Palæomylus*.

The following specimens are all from the Conodont bed (Genesee), at Eighteen Mile Creek, near North Evans, Erie County, N. Y.; collected by W. L. Bryant.

E 2446 Right lower dental plate (Pl. 41, figs. 1, 2). The oral margin is preserved from the beak to a distance 2 or 3 cm. behind the second tritor, and shows well the structure of these parts. The beak, under a lens, shows tritoral columns rising to the surface. In the second tritor, the worn surface is much convoluted by narrow, line-like ridges arranged in curves and circles. Length, as far as preserved, measured along oral margin, 9 cm.; width of oral margin immediately in front of first tritor, 25 mm.; tip of beak to origin of first tritor, 31 mm.; anterior margin of first tritor to origin of second, 24 mm.; width of symphyseal area, 27 mm.

E 2453 Beak of a left lower dental plate belonging to a specimen of about the same size as the preceding. (Pl. 41, figs. 1, 2, part.)

E 1929 and E 1930 Fragments of three dental plates showing portions of the oral surface and the second tritor. (Pl. 41, figs. 3–5.)

E 2452 Beak of a left lower dental plate.

E 2447 Tritoral region of a dental plate, much worn by use.

Palæomylus sp. [Juvenile?]

(Pl. 40, figs. 4, 5)

E 2448 A small dental plate with the greater portion of its outer face embedded in matrix. Total length 29 mm.; height at beak 13. The beak is clear of matrix on all sides and well preserved. This and the functional margin are considerably worn. A striking feature about the element is that the outer and the symphyseal faces are at right angles to each other, forming a sharp ridge along the front of the beak.

This element is probably a juvenile dental plate of *Palæomylus*. The reasons for referring it to this genus are: (1) its general form and the presence of two small tritors back of the beak; (2) the fact that the tritoral region shows the ends of tritoral canals forming the characteristic ptyctodont rugose wearing surface.

Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

E 2449 Impression of the oral margin of a small palæomylid dental plate, together with a cast made from it. (Pl. 40, fig. 5.) It shows the beak and the two tritors very perfectly.

Pyrite layer of the Tully horizon; Cazenovia Creek, near Springbrook, N. Y. Collected by W. L. Bryant.

Deinodus bennetti. n. gen., n. sp.

(Pls. 42, 43)

E 1856 *Type.*—Dental plate in limestone, shown in outer view; in counterpart. The specimen is slightly defective posteriorly, and also at the upper end of the symphysis.

Formation and Locality.—Onondaga Limestone (Mid. Devonic); Cement Quarry, Buffalo, N. Y. Collected by W. L. Bryant.

Dental plate subrectangular, its depth contained about twice in the length. Functional margin a grinding edge worn on outer face, gradually narrowing toward anterior extremity, which is a sharp beak-like point. Anterior margin straight, without spiniferous process. Outer face of plate ornamented with large, non-stellate tubercles which have a tendency to fuse into irregular masses. Plate thickest posteriorly, thinning anterior-ward.

[*Deinos*, fearful, terrible; *odous*, tooth.]

The species is named for Mr. Lewis J. Bennett, the owner of the Buffalo Cement Quarry, and an Honorary Director of the Buffalo Society of Natural Sciences. To Mr. Bennett's interest in the fossils found in this quarry is due the magnificent collection of Eurypterids in the Museum, regarded as one of the finest in the world, and obtained at considerable expense to him by his paying the workmen premiums for discovering specimens. It was in this quarry also that the type of the present species was found.

Remarks.—These extraordinary dental plates are so unlike any others known, that we have no hesitation in basing a new genus upon them. They apparently belong in the same category with the rhynchodont type of dental plate. But the ornamentation of the outer face is a most extraordinary character, clearly indicating that this face was not covered with soft tissue in life.

In the same formation with these dental elements occur fragmentary plates with similar tubercles, which evidently belong to the same fish. These plates, both in shape and ornamentation, are very suggestive of certain Carboniferous plates and spines from the Mountain Limestone of Armagh, Ireland, figured by J. W. Davis[48a] and ascribed by him to *Oracanthus milleri* Agassiz. In the same rock with these are found spines of the so-called *Oracanthus* which has since been demonstrated by A. S. Woodward[48b] to belong in the family of Gyracanthidæ.

Among the specimens in the Buffalo Museum are three nearly complete spiniferous plates, exceedingly like those figured by Davis, plate 65, figures 3 and 4. In our examples, however, the ornamental denticles are more discrete.

From the same Mountain Limestone, Davis figured under the generic title "*Rhamphodus*," certain problematical dental plates which in profile are exceedingly suggestive of *Rhynchodus*. These dental plates were considered by Davis, and later by Woodward, to

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[48a] Davis, J. W.: On the fossil fishes of the Carboniferous limestone series of Great Britain *Trans. Roy. Dublin Soc.*, [2], I, 525; pl. 62, figs. 3, 4, 7, 13; pl. 65, figs. 3, 4. 1883

[48b] Woodward, A. S.: On a Carboniferous fish fauna from the Mansfield District. *Mem. Victoria Nat. Mus.*, Melbourne, I, 1-32, 1906.

be the front teeth of a Cochliodont shark, and it is a curious fact that Jaekel[48c] later proposed the same generic name for certain Ptyctodont plates indistinguishable from those of *Rhynchodus*.

It is obvious, from the new dental plates of *Rhynchodus* and of *Mylostoma* described in this catalog, that the range of variation among these forms has not hitherto been fully appreciated. These groups apparently varied in many different directions, producing a bizarre series of forms which we are only now first beginning to recognize. Evidence is accumulating that the gap between the Rhynchodonts and the Arthrodires will be bridged when these groups, particularly the first, have become better known.[49] Even among the specimens now in hand, there are a number that puzzle one as to whether they should be referred to the Arthrodires or to the Rhynchodonts.

The following specimens are from the Onondaga limestone (Mid. Devonic). All are from the Cement Quarry—excepting only E 1861, which is from the Park Quarry—Buffalo, N. Y. Where not otherwise indicated, they were collected by Mr. F. K. Mixer.

E 2451	A spine-like element 72 mm. in length, and 18 mm. in width at its wider end, tapering to a point. (Pl. 42, fig. 1.) It is embedded in matrix but can be viewed from three sides; of these the two lateral ones are covered with tubercles, while the face between them is smooth. The denticles are closely crowded, their bases touching, and all point in the same direction,—toward the smooth face. The latter consists of hard, smooth bone, and may have functioned as a tritor. The opposite side, as shown by other specimens, is excavated with roughened vascular surfaces as though for a pulp cavity.
E 1860	Dental plate.
E 1861	Robust, conical, tuberculated, fragmentary tooth or spine.
E 1862	Fragmentary, tuberculated plate. Collected by W. L. Bryant.
E 1863	Fragmentary tuberculated plate.

[48c] Jaekel, O.: Ueber *Rhamphodus*. *Sitzungsber. Ges. Naturforsch. Freunde*, 1903, p. 392.
[49] Dollo, Louis.: Les ptyctodonts sont des arthrodires. *Bull. Soc. Belge de Geol.*, xxi, 12 pp., pl. *ii*.

E 1864 Fragmentary spine-shaped plate, tuberculated on the edges. Collected by W. L. Bryant.

E 2460 Fragmentary plate, in matrix, ornamented with flattened, non-stellate tubercles; perhaps this species (Pl. 43, fig. 1).

E 2461 Pointed dental (?) plate in oral view (Pl. 42, fig. 2). The side walls are ornamented with tubercles, and underneath is a broad cavity extending the entire length of the specimen. Collected by W. L. Bryant.

E 2463 Spine-like plate resembling a specimen figured by J. W. Davis, from Armagh, Ireland (*Trans. Royal Dublin Soc.*, [2], I, pl. 62, fig. 13).

E 2464 Fragmentary plate, probably portion of a dental plate, in matrix. Near one extremity are a few obscure denticles.

E 2466, E 2467 and **E 1868** Three elongated, spine-like plates closely resembling a specimen figured by J. W. Davis (*Ibid.*, pl. 65, figs. 3, 4), excepting that our specimens apparently terminated distally in a conical point.

E 2468 An imperfect, triangular, spine-like element, suggestive of an *Oracanthus* spine. (Pl. 43, fig. 3.)

E 2469 Fragmentary spine-like plate seen in longitudinal section.

E 2493 Sigmoidally flexed plate shaped like an upper dental of *Ptyctodus*, the beak compressed and rounded, and behind it a cutting margin expanding posteriorly into a tritor-like area. Under surface excavated as a pulp cavity. (Pl. 43, fig. 2.)

Ptyctodontidæ indet.

E 2472 Fragmentary dental plate, in matrix, showing a pronounced anterior beak, and a secondary acute cusp a short distance behind it; the latter separated from the beak by a deep, semi-circular excavation.

Conodont bed (Genesee); Eighteen Mile Creek, North Evans, Erie County, N. Y. Collected by W. L. Bryant.

E 2473 Another specimen similar to preceding.

E 1882 and **E 1883** Two dermal plates of the kind frequently associated with rhynchodont dental elements in various Devonic formations, e.g., the Hamilton of Milwaukee, the Cedar Valley limestone of Iowa, the Mid-Devonic of the Eifel district of Rhenish Prussia and the Upper Devonic of Wildungen. They have been regarded by Eastman as belonging to ptyctodonts[50] a view which seems quite probable; but no specimen has yet been found with these plates in position, so as positively to establish this view.

Hamilton limestone; Milwaukee, Wis. Collected and presented by Mr. Edgar E. Teller.

ELASMOBRANCHII

[*Sharks and Rays*]

The sharks, living and extinct, are divisible into four great groups:

1. Pleuropterygii (*Cladoselache*, *Cladodus*, etc.).
2. Acanthodii (*Acanthodes*, *Diplacanthus*, etc.).
3. Ichthyotomi (*Pleuracanthus*, *Diacranodus*).
4. Euselachii[50a] (Example: any living species of shark).

Of these groups, the first three are entirely extinct; the fourth comprises both extinct and living forms.

All four groups are represented by good materials in the Buffalo Museum.

I. Pleuropterygii

In the summer of 1914, Mr. Bryant visited the Cleveland shale locality in Ohio and obtained among other things, nine specimens of *Cladoselache*. Some of them are splendid, complete sharks of great interest and two or three throw light on some of the less-known species.

The species of *Cladoselache* represented in the collection are the following:

1. *Cladoselache acanthopterygius*
2. *Cladoselache brachypterygius*
3. *Cladoselache desmopterygius*
4. *Cladoselache eastmani*

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[50] *N. Y. State Museum, Mem.* 10, p. 73, 1907. One such plate is there figured, pl. i, fig. 6.

[50a] This group name was introduced by O. P. Hay in 1902, to include all the sharks excepting groups 1 to 3 named above. Bibliog. and Catal. N. Amer. Vert. *U. S. Geol. Survey, Bull.* 179, p. 274.

5. *Cladoselache fyleri*
6. *Cladoselache kepleri*
7. *Cladoselache newberryi*

All, excepting *C. eastmani*, which is from New York State, are from the Cleveland shale (Upper Devonic), near Cleveland, Ohio.

Cladoselache acanthopterygius Dean

(Pl. 45, and text-fig. 43)

[Mem. Amer. Mus., ix, 240, fig. 27, 1909]

This is one of the rarest of the Cleveland shale sharks, easily recognized by its narrow pectoral fins. A single specimen is in the collection.

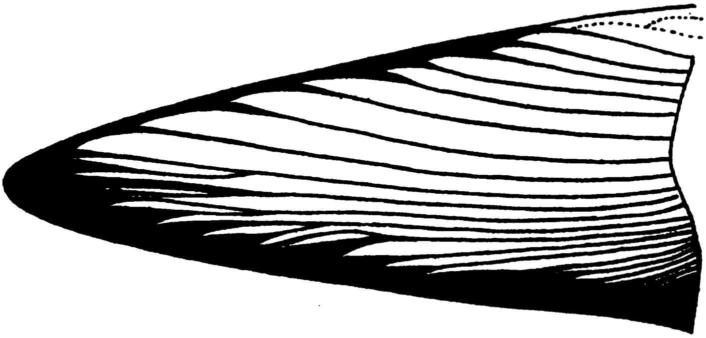

FIG. 43. *Cladoselache acanthopterygius.* PECTORAL FIN, NATURAL SIZE. E. 2474

The name *acanthopterygius*, is not a happy one, since it suggests the presence of a spine on the fin, which of course is not the case with any Cladoselachian; nor is the pectoral fin itself quite so narrow as to resemble a spine (see fig. 43).

E 2474 A large shark lacking the head. It shows the entire body as far back as the caudal fin, both pectorals, and the caudal lateral keels. A number of cladodont teeth are included in the body in the region back of the pectorals; they are either remains of a smaller shark which had been ingested, or teeth which have become shifted from the jaw region of this specimen.

Measurements:	*cm.*
Distance from pectoral fins to tip of caudal	45.0
Span across pectorals	26.0
Base of pectoral	3.5
Length of pectoral	9.0

As seen from these measurements, the pectoral (fig. 43) is nearly three times as high as wide, and can therefore be compared only with that of *C. acanthopterygius.* It has 14 to 16 primary rays and 8 secondaries; the latter are closely crowded and partly overlap. Tertiary rays, if present, cannot be distinguished in this specimen.

Cladoselache brachypterygius Dean

(Pl. 46)

[Mem. Amer. Mus., ix, 240, pl. xxxii, and text-figs. 22, 23, 1909]

E 2475 We refer to this species a large, fairly well-preserved shark about 3½ feet in length, lacking the caudal extremity. We base our determination on the relative shortness of the pectoral fins, and on their ray formula. The specimen shows both pectoral fins, and a single dorsal. The latter lies in a plane at right angles to that of the pectorals. The pectoral is broad in proportion to the size of the fish, its base measuring about 14 per cent. of the total length of the shark. In the head region, the orbits, jaws and teeth are preserved, and farther back are some muscle segments. The ventral fins are not preserved.

The pectoral fin is relatively short, its height being only a little greater than its base, due to the prolongation of the fin-fold. Its extremity is broadly rounded, not drawn out to a point. The hinder web extends beyond the rays, and is prolonged for a short distance along the side of the body. The fin has 21 primary, 9 secondary, and 2 tertiary rays.

The position of the dorsal seems to be more forward in this species than in *C. fyleri.* This fin shows 19 primary rays, rather crowded together, but no secondary rays can be distinguished.

Measurements:	cm.
Length, as far as preserved (to a short distance posterior to origin of caudal keels)	69.0
Tip of stout to origin of caudal	64.0
Tip of snout to line through origin of pectorals	18.0
Span across pectorals	33.0
Base of pectoral	10.5
Length (that is, height) of pectoral	12.0
Point midway between termination of pectoral membranes to origin of dorsal	7.0
Base of dorsal	7.0
Height of dorsal	7.5

Cladoselache desmopterygius Dean

(Pl. 47, and text-figs. 44, 45)

[Mem. Amer. Mus., ix, 240, pl. xxix, and text-fig. 24, 1909]

This species is distinguished from *C. fyleri*, to which it is most closely related, by its relatively larger fins, their difference in radial formula, and by other points brought out in the description of the individual specimens below. The species is represented in the collection by three specimens.

E 2476 Front half of a shark of medium size. It shows only one of the pectorals (fig. 44), and but one ventral. The head, which is well-preserved, seems to have been more pointed, at least as far as the state of preservation of the specimen indicates, than in some of the other Ohio cladoselachians. It exhibits seven robust gill arches; and there are eight or nine banks of teeth shown in the left half of the jaw. There seems no doubt that this specimen is correctly referred to *C. desmopterygius*.

The pectoral has 19 primary rays, 12 secondaries and 14 tertiaries; the ventral, 9 primaries and 2 secondaries.

Measurements:	cm.
Tip of snout to origin of pectoral	20.0
Distance between posterior termination of pectoral and origin of ventral	19.5
Base of pectoral	7.5
Length of pectoral	9.2
Base of ventral	3.0
Length of ventral	2.0

E 2477 A nearly complete fish. It exhibits only a single pectoral, and this is partly destroyed owing to its having been exposed in the concretion and having become weathered before it was collected. It shows both orbits indicated by the sclerotic rings; several (at least five) banks of teeth, (it is seen that these teeth overlap at their bases); also neural arches, and fossilized muscle-tissue, arranged in segments, near the pectoral fins. In the region of the alimentary canal some ingested matter is to be seen, including scales, and a striated tooth (the latter destroyed in cleaning the specimen).

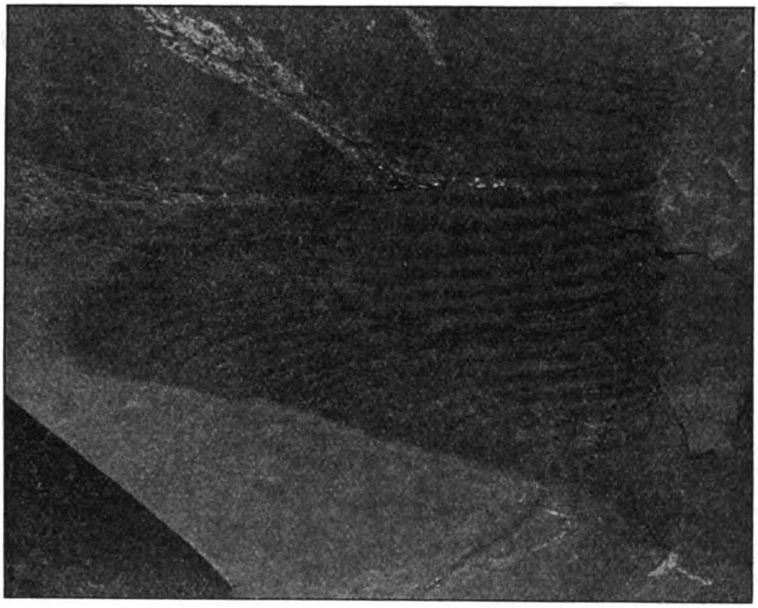

FIG. 44. *Cladoselache desmopterygius*. PECTORAL FIN OF SPECIMEN E. 2476

The pectoral fin is large, elongated, and situated relatively far back, as is characteristic of this species. It shows 20 primary and 4 secondary rays. There are also indications of tertiary rays, but they cannot be counted.

E 2478 Body of a shark, with the pectorals, ventrals, and one dorsal (fig. 45), probably belonging to *C. desmopterygius*.

The pectorals are fairly well preserved. They show 19 or 20 primary, 8 secondary, and 8 tertiary rays. There were probably several additional tertiaries, but they are not shown. The shagreen covering the pectoral fin is present in places, and the fin itself seems thick and fleshy. Both ventral fins are preserved. They are rather small, and broken posteriorly, but probably ran out into narrow membranes along the margins of the body. They show 9 or 10 primary, and 6 secondary rays; there are, apparently, no tertiaries. In addition to the pectorals and ventrals, there is another fin present, evidently the dorsal. It is situated 11.5 cm. behind the posterior margin of the pectoral. It shows 10 primary rays and 5 secondaries; its height is 3 cm., and base 3.5.

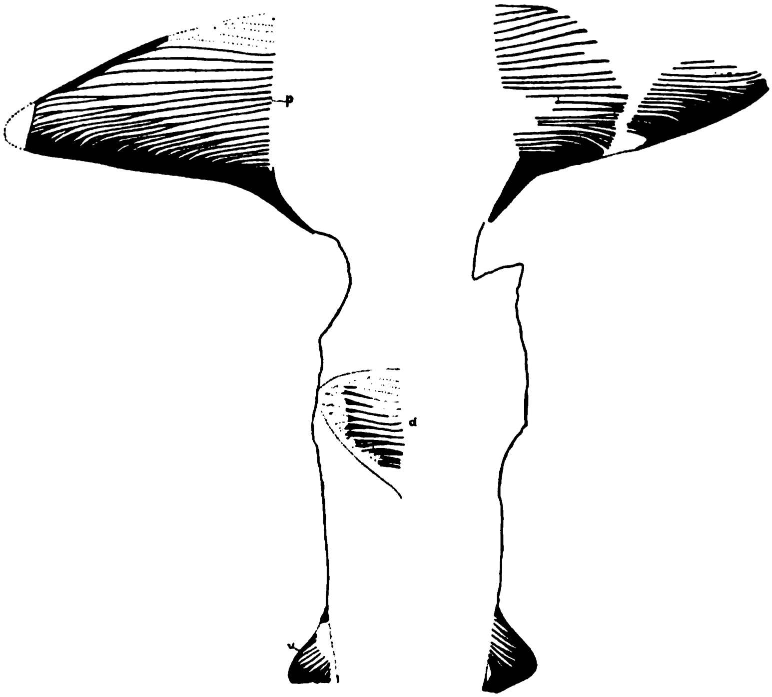

FIG. 45. *Cladoselache desmopterygius.* BODY OF A SHARK, DISPLAYING THE PECTORALS (*p*), VENTRALS (*v*), AND ONE DORSAL (*d*). × ¼. E 2478

Measurements:	*cm.*
Base of pectoral	10.5
Length of pectoral	13.0
Span across pectorals (restored)	38.0
Span across ventrals	12.0
Base of ventral	4.0
Height of ventral	2.5
Posterior termination of pectoral membrane to origin of ventral	19.5

Cladoselache eastmani Dean

(Text-fig. 46)

Cladoselache sp. indet., EASTMAN, N. Y. State Museum, Mem. x, 57, pl. 8. 1907.

Cladoselache eastmani DEAN, Mem. Amer. Mus. Nat. Hist., ix, 240, text-fig. 25 [figured upside down]. 1909.

This species is known only by a pectoral fin, preserved in the Buffalo Museum. The specimen is of great interest since it is the only

FIG. 46. *Cladoselache eastmani.* PECTORAL FIN. TYPE AND ONLY KNOWN SPECIMEN. × about ⅔. E 2027

example of *Cladoselache* thus far found in New York State, and with one other exception,[51] the only one found in any formation outside the Cleveland shale of Ohio.

E 2027 A fin of large size, the base measuring 180 mm. and its length 260 mm. It is remarkable for its narrow pointed form, and for the large number of rays, which are very slender, and about 80 in number. Secondary and tertiary rays are apparently absent. It represents a shark about 4 feet in length.

It should be pointed out that while this specimen is close to *Cladoselache*, and may for the present be left in that genus, still its narrowness, the great number of its rays which far exceeds that found in any other species of *Cladoselache*, may ultimately necessitate its being placed in a distinct genus.

From a concretion found in the Rhinestreet shale, shore of Lake Erie at the mouth of Eighteen Mile Creek, Erie County, N. Y. Collected by Dr. Herbert U. Williams.

Cladoselache fyleri (Newberry)

(Pl. 48)

This is the most abundant species of shark in the Cleveland shales. It is represented in the collection by a splendid specimen.

E 2480 A complete shark shown in ventral view, with the pectorals expanded. The ventrals are missing. The caudal is seen in section. In the precaudal region the horizontal keels are beautifully shown, standing out sharply through the contrast of their black color. In the head region the jaws are shown, although somewhat shifted from their proper position. A number of teeth are present; they exhibit fine striations on the central cusps, and in some of them extremely small denticles are present between the main and the lateral cusps. The sclerotic rings are well preserved. The pectoral shows 20 primary rays and 8 secondaries; no tertiaries are apparent.

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[51] **The other exception is a caudal fin in a small nodule from the Waverly (basal Carbonic) of Kentucky [No. 7583 Amer. Mus.].** ***Mem. Amer. Mus. Nat. Hist.*****, ix, 241, fig. 17.**

Measurements:	cm.
Total length	39.0
Tip of snout to line through origin of pectorals	8.0
Span across pectorals	14.0
Base of pectoral	3.5
Length (that is, height) of pectoral	4.5

Cladoselache kepleri (Newberry)

(Pls. 49, 50; text-figs. 47, 48)

This is the largest of the Ohio Cladoselachians, reaching a length of 6 feet. Its large fins, with broad, stout rays, are usually in magnificent preservation, and show the details of the fin structure better than any other species. This form is represented in the Buffalo Museum by a fine specimen over 5 feet in length, and by a portion of a second, consisting of the region of the ventral fins.

E 2481 A nearly complete shark showing the head and almost the entire body as far as the tail; both pectorals, one ventral, and the upper lobe of the caudal. The specimen shows considerable detail: the eyes, teeth, branchial bars, neural arches and shagreen (Pl. 49).

The pectoral is somewhat longer than wide at the base, the ratio being 9 to 7. The rays are clearly shown; there are 20 primaries, 10 secondaries and 3 tertiaries.

The ventral is not perfectly preserved at its posterior extremity, but the web was apparently drawn out into an elongated, pointed flap, as in other species in which it has been observed. It exhibits 14 primary rays and 3 secondaries; there are no tertiaries.

Measurements:	cm.
Length as far as preserved	160
Length, to (about) origin of caudal	156
Tip of snout to line through origins of pectorals [about 21 per cent. of length of fish]	36
Tip of snout to line through origin of ventral	93
Base of pectoral	14
Length (or height) of pectoral	18
Base of ventral	10+
Length (or height) of ventral	7

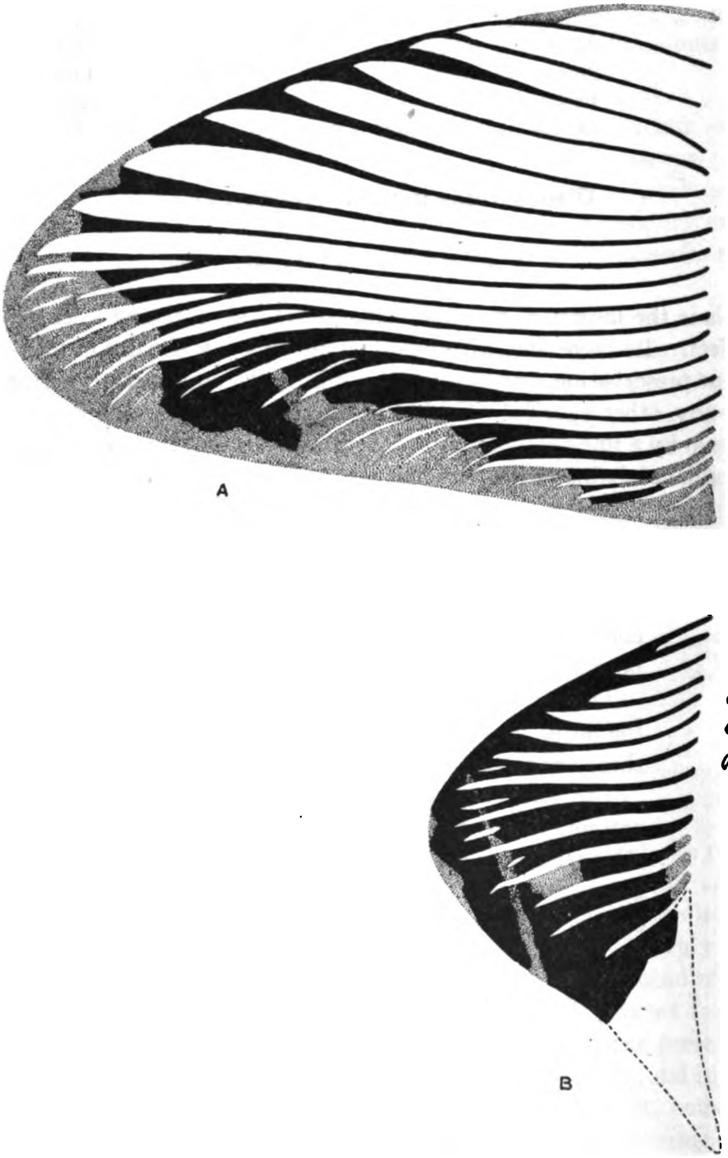

FIG. 47. *Cladoselache kepleri.* *A*, PECTORAL; *B*, VENTRAL; BOTH OF THE SAME SHARK. × ⅓. Stippled portions restored. E 2481

E 2482 Portion of the body of a large shark with the ventral fins, in counterpart (fig. 48). One of these is exquisitely preserved, and exhibits for the first time in this species the narrow posterior prolongation of the web. The base of the ventral measures 16 cm. (including the web to its posterior end); its greatest height is 9 cm.; the span across the ventrals is 34 cm. Our identification of the species as *C. kepleri*, is based on the large size of the shark and on the robustness of the fin-rays. There are 13 primary rays, 5 secondaries, but no tertiaries.

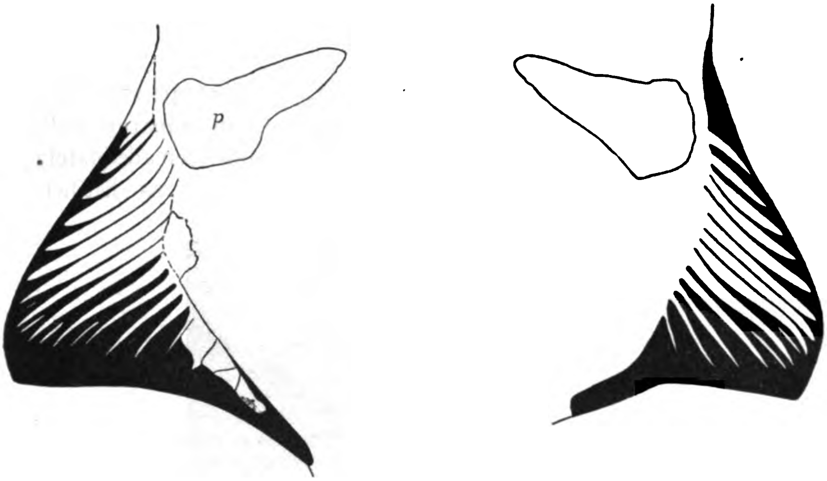

FIG. 48. *Cladoselache kepleri*. VENTRAL FINS, × ⅜. *p*, pelvic fin-support. E 2482. (See Pl. 50)

This specimen exhibits one of the most perfectly preserved ventral fins ever found. There are only two other examples of ventral fins known that compare with it—one in the American Museum,[52] the other in the British Museum.[53] Both of these are ventrals of *Cladoselache fyleri*, and neither shows the details of structure quite so clearly as the present specimen. In the American Museum specimen there is no cartilaginous rod extending into the posterior prolongation of the fin-web. In the British Museum specimen it is present, but not so clearly demarcated posteriorly. Prof. Jaekel terms it the "Haupt-

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[52] No. 7019 Amer. Mus. *Mem. Amer. Mus. Nat. Hist.*, ix, 224, figure 19, 1909.

[53] Jaekel, O.: Ueber die Beurteilung der paarigen Extremitäten. *Sitzungsb. d. k. Preus. Akad. Wiss.*, xxvi, 707–724, 1909. See especially pp. 713–714, and figure 5.

achse," and represents it as extending the whole length of the web, and, in fact, projecting a little beyond. He regards it as a myxopterygium, and says it terminated in small hooks.[53]

In our specimen the axial rod begins at a distance of 110 mm. behind the anterior extremity of the fin base, and it has a length (measured from the posteriormost radial) of 50 mm. It shows two or three very vague transverse lines; but these are probably mere breaks in the superficial film of the fossil and not an actual segmentation of the rod.

Cladoselache newberryi Dean

(Text-fig. 49)

This species has hitherto been known only by the type specimen, an incomplete small shark, which is perhaps only an immature individual of some other Ohio species. Its status has not been adequately defined, but for the present we retain it provisionally as distinct.

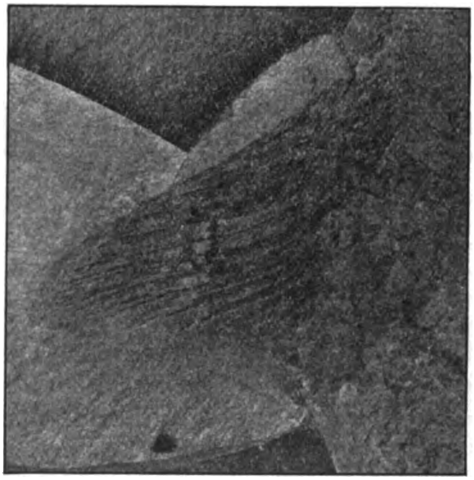

FIG. 49. *Cladoselache newberryi.* PECTORAL FIN, NATURAL SIZE

The posterior margin was outlined in pencil in the specimen before photographing. E 2483.

E 2483 A fragment of a shark exhibiting both pectorals. The base of the pectoral (fig. 49), measures 6.5 cm., and its length 5 cm. It shows 13 primary, and 2 or 3 secondary rays, but no tertiary rays are to be seen. The fin is rather pointed, and the web is prolonged posteriorly beyond the last ray into a fin-fold, about half as long as the base proper, of the fin.

Family CLADODONTIDÆ

Cladodus coniger Hay

E 2078-9 We refer to this species the impressions of two imperfect teeth from the Catskill beds in Crawford County, Pennsylvania. Each tooth consists of a central cone and two denticles on either side of it, directed laterally. The crowns are marked by striations or carinæ. This species has hitherto been known only from the Chemung.

Top layer of the Second Mountain Sandstone (Catskill); Snodgrass Quarry, Crawford County, Pennsylvania. Collected by J. F. Carll.

Cladodus urbs-ludovici Eastman

(Pl. 44, figs. 1, 1a)

Cladodus urbs-ludovici EASTMAN, Devon. Fishes Iowa, 110, pl. iii, fig. 3. 1908.

Three cladodont teeth from the Conodont bed represent this species, which was hitherto known only by the holotype. an imperfect tooth, from the New Albany shale (Genesee) of Kentucky. It is interesting as adding another to the three or four species common to the New Albany shale and the Conodont bed.

Since the original description of the species was based on a single imperfect tooth, which did not show the root well, and also lacked the distal half of the crown, it seems desirable to give a revised description of the species, based on our three specimens.

Description.—Tooth a large, somewhat compressed cone, rising from a laterally expanded base. No lateral denticles. Crown elliptical in cross-section, with sharp lateral keels; the posterior face somewhat more convex than the anterior. Both faces ornamented with very fine, parallel, vertical lines which end abruptly at the merging of the crown and base. Apex of crown reflexed slightly forward. Base rather compressed antero-posteriorly, laterally expanded, with its outer extremities apparently directed somewhat downward; upper surface of base, near cone, rounded.

E 1899 Tooth, 12.5 mm. in height, on a piece of matrix.
Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

E 1900 Tooth, 20 mm. in height, free from matrix. Other data same as preceding.

E 2484 An acutely-pointed tooth, lacking the lateral extremities of the root, in matrix. Height, 16 mm.; width of cone, at base, 5 mm. Other data same as preeeding.

II. Acanthodii

The Acanthodians are not as abundantly represented in America, either in species or individuals, as in Europe. There are only a few specimens in the Buffalo Museum. These include a fine example of *Acanthodes concinnus;* a fin-spine from the Conodont bed, and two spines of *Gyracanthus*. The last are now positively known to be Acanthodians through having been found in their natural position in unquestioned Acanthodian sharks, from the Carbonic of Victoria, Australia described by Smith Woodward, in 1906,[54] under the name *Gyracanthides murrayi*. Dr. Woodward separated these Acanthodians from the rest as a distinct family—*Gyracanthidæ*.[55] Some of these forms, judging by the size of the pectoral spines, must have reached considerably larger proportions than the other Acanthodidæ, attaining a length of several feet.

It has been suggested, also, that the spines known as *Machæracanthus* probably belonged to Acanthodians. This view is highly probable; indeed it may be regarded as almost established, in view of the close resemblance between certain of the smaller species of *Machæracanthus* and the fin-spine of Acanthodians; and also the approximation of some of the species to certain *Gyracanthus* spines. But as none of these spines has yet been found in natural association with the fish to which it belonged, there must still remain a slight uncertainty; and hence we follow the older view of placing the genus *Machæracanthus* among the Ichthyodorulites.

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[54] Woodward, A. S.: On a Carboniferous fish fauna from the Mansfield District, Victoria. *Mem. National Mus.*, Melbourne, 1, pp. 1–32, pls. i–xi, 1906.

[55] *Loc. cit.*, p. 3.

Acanthodes concinnus Whiteaves

(Pl. 51, figs. 2, 4; text-fig. 50)

Among the specimens collected by Mr. Bryant in the Upper Devonic at Scaumenac Bay, Quebec, in 1915, is a large example of *Acanthodes concinnus*, 29 cm. in length. This is about twice the size of the largest specimen figured by Whiteaves,[56] and thus proves that the species attained much larger proportions than was hitherto supposed. The species is readily distinguished by the scale ornamentation (Pl. 51, fig. 2), and by the relatively weak spines.

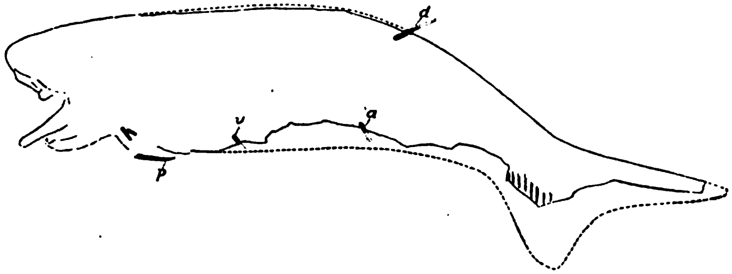

FIG. 50. *Acanthodes concinnus* Whiteaves. OUTLINE OF A NEARLY COMPLETE SHARK. × ⅓

All the fin-spines are present (although incompletely preserved), and apparently in their proper positions.

a, anal fin-spine; *d*, dorsal; *p*, pectoral; *v*, ventral. The two fragments of spine seen in front of the pectorial spine are apparently parts of the fin-spine of the opposite side. Note the ray-like structure in the lower lobe of the caudal. E 2485

E 2485 A shark, 29 cm. in length (fig. 50), in side view, on shale. The ventral margin of the trunk was lost through the flaking out of a thin superficial layer of the rock; and the tip of the caudal for about 1 cm. is also missing. The mouth is widely opened. One pectoral fin-spine is the only spine completely preserved (Pl. 51, fig. 4). It is somewhat shifted from its natural position, and measures 19 mm. in length (incomplete at proximal end?). Of the other fin-spines only the proximal ends are preserved. The dorsal spine is inserted a little back of the middle of

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[56] Whiteaves, J. F.: Illustrations of the fossil fishes of the Devonian rocks of Canada. Part I. *Trans. Roy. Soc.* Canada, iv, 107, pl. x, figs. 1, 1a, 1886; Part II, in vol. vi, pl. v, fig. 2, 1889.

the fish; the anal spine, slightly in front of the dorsal; the ventral spines, a little nearer the pectoral than the anal. The caudal had a long upper lobe; its lower lobe shows the impressions of a number of radials.

The shagreen is well shown over most of the fish; its ornamentation (Pl. 51, fig. 2) agrees closely with that figured by Whiteaves.[57] In the caudal extremity, the scales of the lateral line are well shown.

Upper Devonic; Scaumenac Bay, near Village of Migouasha, Quebec, Canada. Collected by W. L. Bryant, August, 1915.

Acanthodian Fin-spine

E 2486 A small spine in matrix (Pl. 51, fig. 3). Length as far as preserved 18 mm.; width, 3 mm. There seems no doubt that this is an Acanthodian spine.

Conodont bed (Lower Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Family GYRACANTHIDÆ

Gyracanthus sarlei, n. sp.

(Pl. 52, figs. 3–5)

E 2487 *Type.*—Proximal half of a small spine, on a piece of shale. Length as far as preserved, 38 mm.; maximum width, 9.

Formation and Locality.[58]—Genesee shale; Canandaigua Lake, N. Y. Collected by Prof. Clifton J. Sarle.

Spine small, 5 or 6 cm. in length. Cross-section an irregular oval, with its narrower side drawn out to a point. Sides ornamented with two sets of striæ, forming V's whose apices are on the rounded ridge running the length of the spine; the striæ on the thin, wing side of the axis, long, smooth and very little inclined toward the axis, while the striæ on cutwater side of spine are shorter, more or less wavy in places,

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[57] Loc. cit; Pl. x, fig. 1 a.

[58] There was some uncertainty as to the horizon of this specimen, and we submitted it to Prof. A. W. Grabau, of Columbia University, for examination. He pronounced the matrix to be "undoubted Genesee shale." There are two specimens of *Leiorhynchus quadricostatus* on the same piece of rock.

and form a large angle with the axis. Outer half of the thin, wing side of spine smooth, without ornamentation; on cutwater side ornamentation extends clear to the margin.

Named for Prof. Clifton J. Sarle of St. Lawrence University, Canton, N. Y., who collected this and other specimens now in the Buffalo Museum.

Remarks.—This species differs from the three other American Devonic species known. It is closest to *Gyracanthus primævus* Eastman,[59] from the Marcellus shale; which, however, besides being from a lower horizon, differs in several important points. In *G. sarlei*, the ornamentation extends clear to the cutwater margin, whereas in *G. primævus* there is "a smooth and highly polished enamelled band, adjacent to the front margin." On the other hand, conditions are reversed as regards the ornamentation of the thin, wing margin; in *G. sarlei* the outer half of this margin is smooth and unornamented, whereas in *G. primævus* it is ornamented up to the edge. In *G. sarlei* moreover, the ornamental striæ on the wing half of the spine are less inclined to the axis, being only the least bit off the true vertical, and there are no beadings or tuberculations on the striæ adjacent to the inserted portion as in *G. primævus.*

From *Gyracanthus incurvus* Traquair,[60] from the Lower Devonic of Campbelltown, N. B., *G. sarlei* is distinguished by differences in ornamentation and other details.

From *G. sherwoodi* Newberry, from the Chemung and Catskill of New York and Pennsylvania, it is distinguished by its smaller size, by the striæ being much less inclined to the axis of the spine, and by the absence of tubercles or beading from them.

It is worthy of note that *Gyracanthus sarlei* has considerable resemblance to *Machæracanthus*, and if not for the distinctive *Gyracanthus* ornamentation, would be regarded as a species of this genus. Thus it has a *Machæracanthus*-like cross-section, and a smooth lateral wing, which thins out to a knife edge, as in this genus. It has long been known that *Machæracanthus* has much resemblance to Acanthodian spines; and the present specimen on the one hand, and *Machæracanthus sulcatus* (which has an ornamentation of lines running parallel with the axis of the spine) on the other, help to bridge the gap between these two genera.

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[59] Devonian fishes of Iowa, 114, and text-fig. 17, 1908.

[60] For a figure of this species see Woodward, A. S.: On the Lower Devonic fish fauna of Campbelltown, N. B. *Geog. Mag.*, [3], viii, 1–6, pl. i. figs. 4–5, 1892.

Gyracanthus sp.

(Pl. 52, fig. 4)

E 2489 A small, slender spine, imperfect at both ends, measuring 46 mm. as far as preserved. One face is rounded while the other has a sharp ridge running the length of the spine, somewhat nearer one margin than the other. It is ornamented with two series of fine lines forming a V-shaped arrangement, with the apices of the V's on the ridge. The spine, from its form and ornamentation, undoubtedly represents a species of *Gyracanthus*; but as it may be an immature example, or possibly belongs to *G. sarlei*, it seems to us undesirable to give it a name at the present time. No doubt larger and better specimens will some day be discovered.

Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

III. Ichthyotomi

Genus **Dittodus** Owen[61]

The teeth referred to the genus *Dittodus* belong to Pleuracanth sharks. It is probable that they represent a number of genera, considering their great geological range and the fact that they come from such diverse localities and formations; it therefore seems desirable to retain *Dittodus* as a provisional genus rather than to refer all these teeth to the genera *Pleuracanthus* and *Diacranodus*.

Dittodus priscus (Eastman)

(Pl. 44, figs. 3, 3a, 3b; text-fig. 51)

Diplodus priscus Eastman, Journ. Geol., vii, 490, pl. vii, figs. 1, 2. 1899.

This species has hitherto been found only in a peculiar deposit[62] of Upper Devonic age near Elmhurst, Illinois. Associated with it is a second species, *D. striatus*, distinguished by having much finer stria-

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[61] As pointed out by O. P. Hay (*Bibl. and Cat. Fossil Vert. N. A.*, p. 265), *Diplodus* is preoccupied and should be replaced by *Dittodus* Owen, which is an available synonym.

[62] Weller, Stuart: A peculiar Devonian deposit in northeastern Illinois. *Journ. Geol.* vii, 483–488 3 figs. 1899.

tions. It is remarkable that the same two species should also be found associated in the Conodont bed at Eighteen Mile Creek.

We have 17 teeth of *D. priscus*, some of them in splendid preservation, showing the entire root, the median denticle and all the characters of the species. These specimens enable us to add somewhat to the account given by Eastman, who had available only imperfect specimens. In the first place, it should be observed that there is considerable variation in size among the teeth, some of the larger ones being twice as high as the smaller ones. Secondly, the ornamentation, which consists of striæ spiraling gently upward from base to tip of tooth, varies considerably in the number and prominence of the striæ. Some teeth have seven or eight striæ, others as many as a dozen or more. Frequently short striæ are interpolated between the long ones in the basal portion of the tooth; or the striæ may be reduced on the posterior face, sometimes to only a few short ones confined to the lateral margins. In all the specimens in hand, the central portion of the posterior face is perfectly smooth.

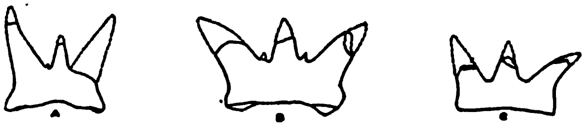

FIG. 51. *Dittodus priscus* Eastman. THREE TEETH. NATURAL SIZE. E 1901

A, a typical *Dittodus* tooth, i.e., with two large lateral cones and an intermediate denticle. B, a tooth with the median denticle rather large and a minute denticle between it and each lateral cone. This tooth is of the form usually placed in the genus *Phœbodus*. C, a tooth with rather large median denticle but no minute denticles between it and the lateral cones. This is also a *Phœbodus* type of tooth.

Eastman described the teeth as round in section. From our series it appears that there was some variation in this regard; most of the teeth are slightly compressed, and some at least, have sharp lateral keels. There is also considerable variation in the height of the root, as viewed from in front. In some teeth it is less than the height of the median denticle, in others it is considerably more. The median denticle varies greatly in size in different teeth; it may be quite small, but generally it is large; in two or three examples it is nearly as large as the lateral cones (fig. 51, C). There may be, too, minute denticles between the medium and the lateral cones, producing teeth that if found alone would undoubtedly be ascribed to the genus *Phœbodus*.

E 1901 Nine teeth, varying from 10 to 13 mm. (15 if restored) in height from lower margin of base to apex of principal cones. One shows the complete root with the "button;" another, which lacks the distal halves of the cones and the posterior portion of the root, has a large central denticle, nearly as large as the principal cones. This tooth is of the kind usually referred to the genus *Phæbodus*; but there can be no question that it is of the same species as the other teeth in this lot. The ornamentation is nearly effaced, but it was apparently similar to that in the other teeth. Another tooth lacks all trace of a median denticle; and still another, has a minute denticle on either side, between the median and the lateral cones.

Conodont bed (L. Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

E 1902 Seven teeth, from 9 to 14 mm. in height; 5 have the root well preserved. These teeth have finer striations than the preceding.

Other data same as preceding.

E 2490 One cone with portion of the root of a large tooth, in matrix.

Other data same as preceding.

Dittodus striatus (Eastman)

Diplodus striatus EASTMAN, Journ. Geol., vii, 490, pl. vii, figs. 3, 4. 1899.

This species occurs in the Conodont bed associated with *D. priscus*, but it is very much rarer, there being only a single specimen in the collection. The species was originally described from "only a few fragmentary specimens," and was stated to attain about twice the size of *D. priscus*. Our specimen is a perfect tooth, and smaller than large examples of *D. priscus*. It is distinguished from the latter more especially by the much finer and much more numerous striæ. In our specimen the striæ are not so strongly curved around the tooth. as in the type figured by Eastman.[63] However, as there, no doubt, was variation in this regard, and since our specimen so closely agrees

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[63] *N. Y. State Mus., Mem.*, 10, pl. i, fig. 11.

with the description and figures of the type, we do not hesitate to refer it to *D. striatus.*

E 2491 A complete tooth. Total height, 5.5 mm.; width of base, 6; antero-posterior diameter of base, 4.5.

Conodont bed, (Genesee), Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Dittodus grabaui, n. sp.

(Text-fig. 52)

E 1910 *Cotypes.*—Five small teeth, free of matrix.

Formation and Locality.—Conodont Bed (Lower Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Teeth small, 2 to 3 mm. in height, with two or three principal cones, and usually a minute denticle between the median and each outer cone. All cones perfectly smooth, without striations on either the inner or outer face. Root, viewed from in front, broader than high, its height to base of median denticle slightly less than height of outer cones; expanded downward at external margins; a "button" present.

Remarks.—Of this species we have a series of about 50 teeth. Although unquestionably all of one species, they show considerable variation in the size and number of denticles, so that one may arrange them into a progressive series leading from *Dittodus* at one extreme, to *Phœbodus* at the other. The first stage (fig. 52, *A*) is a typical *Dittodus* tooth with two principal cones and a smaller denticle between them; the next is a stage with the median denticle somewhat enlarged; the next (fig. 52, *C*) is like the preceding but with a minute denticle between the median cone and each of the outer cones. Finally we have a tooth (fig. 52, *E*) with three principal cones, the median one being also enlarged, and a pair of minute denticles between the median and each of the outer cones; in other words a *Phœbodus* tooth. (Not as well shown in figure 52, *E*, as in some other specimens in the collection.)

This series demonstrates clearly that *Phœbodus* merges into *Dittodus*. From the studies of Fritsch,[64] also, it is known that in the Pleura-

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[64] *Fauna der Gaskohle und der Kalksteine der Permformation Böhmens*, vol. iii, pl. xciv, fig. 1 (*Pleuracanthus parallelus* Fr.), 1895.

canthidæ the small teeth at the angles of the jaws, and those on the gill-bars, were not of the *Dittodus* form, but had 3, 4 or more cones of about equal size. Some of these were of the form usually referred to *Phœbodus*, although unquestionably Pleuracanth as shown by their position in the mouth of a Pleuracanth. Then, too, there are species of *Dittodus* on record that have more than the usual two large cones—for instance, *Dittodus duplicatus* (Newberry and Worthen),[65] which has sub-equal denticles; and there are two species, mentioned by Agassiz in his *Poissons Fossiles*, one with four,[66] and the other with five[67] denticles.

From this it appears that teeth which could be referred to *Phœbodus* occur associated with *Dittodus* in the dentition of one fish. And from all the specimens in hand it appears that a progressive series may be arranged, leading by insensible stages from the one genus to the other. Most *Phœbodus* species, it would seem, can be merged in the genus *Dittodus*. The name *Phœbodus* should therefore be retained as a provisional genus only, for teeth of which there is not a sufficient number of specimens to prove their gradation into *Dittodus*.

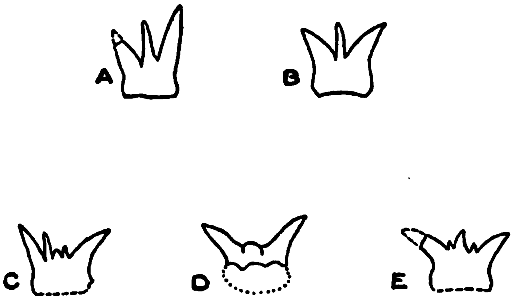

FIG. 52. *Dittodus grabaui*, n. sp. COTYPES. × ABOUT 4

A and *B*, show a large median denticle. *C* and *E*, show minute denticles between the median and lateral denticles. *D*, shows root with the "button."

The species is named in honor of Prof. A. W. Grabau, Professor of Paleontology in Columbia University, as a token of our admiration for his tireless devotion to paleontology, as well as to commemorate his valuable work on the geology and paleontology of Eighteen Mile Creek.

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[65] *Geol. Survey Illinois*, ii, Palæontology, 61, pl. iv, figs. 3, 3a, 1866.
[66] *Dittodus minutus.—Poissons Fos.*, iii, pl. xxiib, fig. 7.
[67] *Ibid.*, iii, p. 204.

Dittodus sp.

E 2028 One tooth, 6 mm. in height, on a piece of black shale. It consists of two cones without a median denticle (perhaps broken away?). The surface of the cones bears a few faint vertical striations, and the tooth may possibly belong in *D. priscus*. The root is injured.

Rhinestreet shale; shore of Lake Erie, near Sturgeon Point, New York.

E 2559 One tooth with fragments of others, somewhat weathered. The ornamentation, if any there was, has entirely disappeared, but in size these teeth are comparable with *D. priscus*.

Pyrite layer of the Tully horizon, Cazenovia Creek, near Springbrook, N. Y. Collected by W. L. Bryant.

IV. Euselachii

Family PETALODONTIDÆ

Petalodus ohioensis Safford[68]

E 2087 One tooth. Bituminous coal series; Northwestern Pennsylvania. Carll collection.

Family PSAMMODONTIDÆ

Psammodus angularis Newberry & Worthen

E 2492 One tooth. Chester limestone? Illinois.

Helodus rugosus Newberry and Worthen

E 2080 One tooth. Carbonic; Crawford County, Pennsylvania. Carll collection

E 2081 One tooth. Carbonic; Franklin, Venango County, Pennsylvania. Carll collection.

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[68] For synonymy of this and the following species, see Hay, O. P.: *Bibl. and Catal. Fos. Vert. N. A.*, 1902, p. 278, *et passim*.

Family COCHLIODONTIDÆ

Synthetodus calvini Eastman

(Pl. 55, figs. 1, 2)

Undescribed dipnoan dental plate—EASTMAN, N. Y. State Mus., Mem. x, 203 pl. iv, fig. 15. 1907.

Synthetodus calvini EASTMAN, Iowa Geol. Surv., xviii, 233, pl. ii, fig. 19; pls. x, xi [in part], xii. 1908.

This species is represented by a single dental plate from the Conodont bed, measuring 46 by 37 mm. (Pl. 55, figs. 1, 2). It agrees well with Eastman's figure of the type (Devonic Fishes of Iowa, Pl. ii, fig. 19), and more especially with his specimen figured in Plate xii, figure 15. The latter figure, which represents a somewhat smaller specimen than ours, might almost have been drawn from ours.

The occurrence of this species in the Conodont bed, is of considerable interest, as it gives us a second species—the other being *Ptyctodus calceolus*—common to this formation and the State Quarry Beds (Upper Devonic) of Iowa.

As regards the nature of these synthetodont elements, which have been described as two species—*Synthetodus calvini* with a single boss, and *S. trisulcatus* with a tripartite division of the wearing surface—we find ourselves unable to concur in the opinion of Eastman that they represent dipnoans. That they are dental plates admits of no doubt; but the dental plates of dipnoans, with their radiating ridges, or rows of tubercles, are among the most distinctive objects known to the ichthyologist; and the present elements are clearly not of that type. They may rather be compared with certain shark dental plates, such as those of *Helodus*. Each element is a flattened plate (Pl. 55, fig. 2), from one face of which rises a boss or tubercle which functioned in triturating, as shown by its wear. And the entire face is covered with a shining enamel (a little worn down on the functional portion), which is sprinkled with small punctæ, such as are seen on the pavement dental plates of various sharks, e. g., *Helodus*. The other face (Pl. 55, fig. 1) of the dental plate consists of bony tissue, roughened with small depressions and postules, and obviously was the side that was set in cartilage, or other soft, nutrient tissue.

Moreover, the elements of both *Synthetodus calvini*, with their single, central boss, and of *S. trisulcatus*, with their tripartite tritor, are bilaterally symmetrical, and there are no rights and lefts among them as would be expected if they were comparable with the usual palatine and splenial dental plates of dipnoans. On the other hand, they are not of the form to compare with dipnoan plates like *Palædaphus*, in which the upper and the lower dental elements are united into single symmetrical plates. The synthetodont elements rather give the impression of belonging to some sort of dental pavement such as is found in certain Paleozoic sharks.

We may mention here that it seems to us also, that the dental plates from the Upper Devonic of Iowa, referred by Eastman[69] to McCoy's genus *Conchodus*, are also not dipnoan, for they show neither rows of tubercles nor ridges. And their small, postero-lateral prolongation regarded by Eastman as the vestige of a dipnoan denticled ridge, is nothing more than the postero-lateral termination found in many forms of grinding shark teeth, for instance, in *Deltodus*. The *Conchodus* elements may belong to the same pavement as the synthetodont plates.

To conclude, from the evidence at hand the dental plates named *Synthetodus* do not show the characteristic structure of dipnoan dental plates. They lack the dipnoan radiating ridges or rows of tubercles. Their bilaterally symmetrical form, large central boss (or its equivalent, the tripartite division of the wearing area), are features strongly suggestive of certain shark pavement teeth, e. g., *Helodus*. And, for the present *Synthetodus* may, provisionally at least, be placed in the shark family Cochliodontidæ.

E 2017 An imperfect dental plate from the center of which rises a large smooth boss (Pl. 55, figs. 1, 2). The surface is highly polished and covered with a scattering of small punctæ. The under side is roughened with depressions and pustules.

Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Acmoniodus clarkei, n. gen., n. sp.

(Pl. 55, fig. 3; text-fig. 53)

One of the most peculiar fish remains in the collection is the specimen from the Conodont bed at Eighteen Mile Creek, represented in Plate 55, figure 3, and in text-figure 53. It is clearly a dental element,

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[69] *Devonian fishes of Iowa*, 228–229, 1908.

but unlike any other known to us, and we describe it here as a new genus.

E 2575 *Type.*—A large dental plate (Pl. 55, fig. 3).

Formation and Locality.—Conodont bed (Lower Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

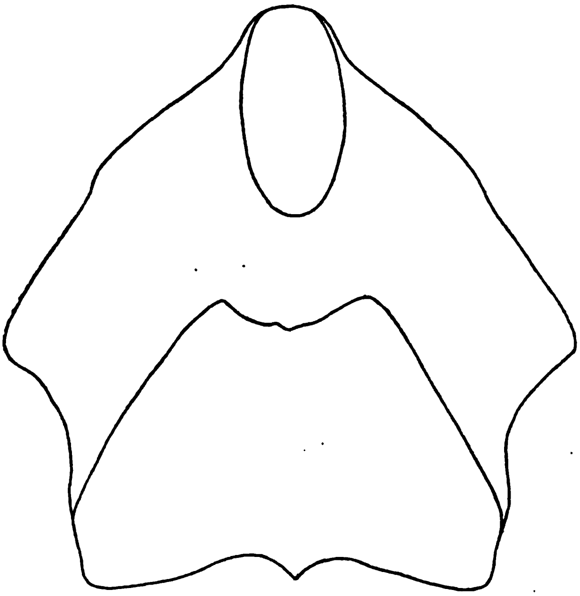

FIG. 53. *Acmoniodus clarkei*, n. gen., n. sp. OUTLINE OF TYPE SPECIMEN TO SHOW FORM OF THE ANTERIOR AND POSTERIOR TRITORS. (See Pl. 55, FIG. 3.) ×¾. E 2575

A large, symmetrical dental plate, having the outline shown in figure 53; with two tritors in the median line, one at the anterior, or front end of the plate, the other occupying the posterior third of the element. Anterior tritor elliptical in outline, with the long diameter in the antero-posterior line of the element; not demarcated from rest of plate but merging gently into it; its upper surface covered with a shining, enamel-like substance and worn by use. On either side of posterior half of front tritor, a shallow depression in the bone, apparently produced by an upper apposing tritor. Posterior tritor shaped like the median-occipital of a dinichthyid, its anterior margin excavated and shorter than posterior one; occupying about one-third the total area of the dental element.

Measurements:	mm.
Length, antero-posteriorly in middle line	112
Greatest width (estimated)	114
Length of anterior tritor	40
Width of anterior tritor	20

[*Akmonion*, a little anvil; *odous*, tooth.]

It gives us great pleasure to name this species for Dr. John M. Clarke, Director of the State Museum and of the Geological Survey of the State of New York.

Family ORODONTIDÆ

Orodus devonicus, n. sp.

(Pl. 44, fig. 4)

E 1903 *Type.*—A tooth, 16.5 mm. broad by 10 mm. long (i.e. antero-posterior diameter).

Formation and Locality.—Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, New York. Collected by W. L. Bryant.

Tooth small, its length (antero-posteriorly) about ⅔ its width. Crown with three low, obtuse denticles, the middle one twice the size of the outer ones; lateral denticles directed forward and outward. Anterior faces of all denticles smooth; posterior and lateral faces covered with fine, raised lines which do not reach to the apices. No punctæ on denticles. Root of the usual orodont form, shelving backward from underneath the front margin of denticles and terminating posteriorly in a straight edge; thickest underneath posterior face of denticles.

Remarks.—Teeth of *Orodus* are common in the Carbonic, and especially abundant in the Lower Carbonic, but they are exceedingly rare in Devonic formations. In fact there is only a single species known from the Devonic—*Orodus elegantulus* Newberry—from the Cleveland shale of Ohio, and even this formation is regarded by some authors as of Waverlyan (Lower Carbonic) and not Devonic age. For this reason the present species from the Conodont bed, is of great interest, as it proves beyond doubt that *Orodus* occurred in the Devonic; and that sharks with a grinding dentition suitable for feeding on hard food existed contemporaneously with the predaceous cladodont-toothed sharks,—*Cladoselache*, *Cladodus* and *Ctenacanthus*.

Orodus devonicus is distinguished from other American species by its low, obtuse denticles, by their style of ornamentation, and by the general proportions and symmetry of the tooth.

Family HETERODONTIDÆ
[Port Jackson Sharks]

Hybodus reticulatus Agassiz

E 2495 A large fin-spine, 29.5 cm. in length; maximum width, 3 mm. Liassic; Lyme Regis, England.

Family LAMNIDÆ
[Porbeagle, Mackerel and Great White Sharks]

Lamna gracilis Agassiz

E 2141 Three teeth. Eocene; S. Carolina.

Odontaspis cuspidata (Agassiz)

E 2142 Two teeth. Eocene; S. Carolina.

Isurus desorii (Agassiz)

E 2137 Three teeth. Eocene; S. Carolina.

E 2138 One tooth. Eocene; Florida. Ottomar Reinecke.

Isurus hastalis (Agassiz)

E 2134 Eight teeth. Eocene; Sienna, Italy.

E 2135 Two teeth. Eocene; S. Carolina.

E 2136 One tooth. Eocene; Florida, Ottomar Reinecke.

Carcharodon auriculatus (Blainville)

E 2133 Six teeth. Eocene; Ashley River, S. Carolina. Presented by Roswell H. Johnson.

Carcharodon megalodon Agassiz

E 2131 Thirteen teeth, the largest 15 cm. in height by 11.5 cm. in greatest width.
Eocene; Ashley River, S. Carolina.

E 2132 One tooth. Eocene; Sienna, Italy.

Family CARCHARINIDÆ

[Dusky Shark, Tiger Shark, etc.]

Galeocerdo lævissimus Cope

E 2144 One tooth. Miocene; Charles County, Maryland.

Hemipristis serra Agassiz

E 2139 Four teeth. Eocene; Ashley River, S. Carolina.

E 2140 Three teeth. Eocene; Phosphate beds, Western Florida. Presented by Ottomar Reinecke.

Family SPHYRNIDÆ

[Hammer-head Sharks]

Sphyrna magna Cope

E 2145 One tooth. Miocene; Charles County, Maryland.

Shark Vertebra

E 2146 Vertebral centrum. Eocene; Phosphate beds, Western part of Florida. Presented by Ottomar Reinecke.

Family PTYCHODONTIDÆ

Hemiptychodus mortoni (Mantell)

E 2127 Two teeth. Niobrara (Cretacic); Monument Station, Gove County, Kansas.

Family SQUATINIDÆ

[Monk or Angel Fishes]

Squatina alifera (Münster)

E 2162 Cast of a fish. Lithographic slate (Upper Jurassic); Eichstädt, Bavaria.

Squatina speciosa von Meyr

E 2161 Cast of the skeleton of a fish on a slab. Lithographic slate (Upper Jurassic); Eichstädt, Bavaria.

ICHTHYODORULITES

Acondylacanthus æquicostatus St. John and Worthen.

E 2500 Spine 150 mm. in length, lacking the inserted portion, and 11 mm. in extreme width. One of the lateral faces is imbedded in the limestone matrix, the other is exposed. The posterior face shows the deeply excavated pulp cavity, bordered by the double row of hooked denticles, which are present for a distance of 113 mm. below the apex. Each lateral face is ornamented by eleven smooth, polished costæ.

Keokuk limestone; Warsaw, Illinois? Purchased, 1915.

Anodontacanthus pusillus, n. sp.

(Pl. 44, fig. 2)

E 1915 *Type.*—A small spine lacking the distal extremity. Length 14 mm. (when complete about 20); greatest width 4 mm.

Formation and Locality.—Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Spine small, straight, gently tapering. Cross-section broadly elliptical toward proximal end, subcircular toward distal end. Pulp cavity completely enclosed, its diameter at proximal extremity of preserved portion one-fifth the diameter of the entire cross-section. External surface incised with longitudinal lines of various lengths, somewhat irregular in direction and occasionally anastomosing. No denticles.

Remarks.—The genus *Anodontacanthus* was established by J. W. Davis in 1881[70] for certain peculiar spines from the Coal Measures of England and Scotland, distinguished by (1) the absence of denticles from the posterior margin; (2) by their straight, tapering form; and (3) their subelliptical to subcircular cross section. A second species was described by Fritsch, in 1889,[71] from the Permian of Bohemia (under the name of *Platyacanthus ventricosus*), and a third by Hussakof, in 1911,[72] from the Permian of Texas. The genus, therefore, had a wide geographical as well as geological distribution. The present species is the first record of it from the Devonic.

These spines are probably head spines of Pleuracanth sharks, and it is not surprising therefore to find them represented in the Devonic, and particularly in the Conodont bed, since teeth of three species of Pleuracanth sharks (*Dittodus*) occur in this formation.

From the previously known species, the present one is distinguished by its very small size, by differences in cross-section, and by the ornamentation of incised lines, which are stronger and more irregular than in the other species, and by the absence of pittings in the striations.

Genus **Atopacanthus**, n. gen.

In 1913 Hussakof[73] described an ichthyodorulite remarkable for its very large denticles, or teeth, along one margin. The species did not fit into any known genus; and since all three specimens in hand were imperfect, it was thought inadvisable to base a new genus upon them. In view of the large size of the denticles and the thinness of the spine itself, the specimens were provisionally placed in the genus *Apateacanthus*, a genus known only by a unique spine from the Devonic of New York State—*A. vetustus* (Clarke).

Among the specimens from the Rhinestreet Shale in the Buffalo Museum, there is a spine of the same character; it throws a little light on these curious elements and enables us to frame a generic definition for them.

The specimen (fig. 54, *A*) is an elongated, spine-shaped element, narrowly elliptical in cross-section, with three teeth preserved along

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[70] On *Anodontacanthus*, a new genus of fossil fishes from the Coal Measures; with descriptions of three new species. *Quart. Journ. Geol. Soc.*, xxxvii ,427, pl. 22, figs. 10–12.

[71] Fritsch, A.: *Fauna der Gaskohle*, Band 3, p. 113, pl. 86, fig. 5.

[72] The Permian fishes of North America, in Case's "Amphibia and pisces of the Permian of North America." Publ. No. 146, Carnegie Institution Washington, p. 162, pl. 26, figs. 5, 5B.

[73] Hussakof, L.: Description of four new Paleozoic fishes from North America. *Bull. Amer. Mus. Nat. Hist.*, xxxii, 245–250, pl. xlvii, 1913.

one margin. The bone itself of the element is also present (not as in the three specimens mentioned above). The teeth are compressed cones, higher than the width of the supporting element, pointed, and compressed in the plane of the element. They bear a few striations in the basal half, somewhat like the teeth of *Holoptychius;* and one tooth that is broken across shows that they have a large pulp cavity.

Taken all in all, the specimen suggests a mandible or other jaw element with teeth, rather than a spine. But the element is narrower in proportion to the height of the teeth than in any mandible known to us. Perhaps it is comparable with such elements as *Edestus*, or the intermandibular series of teeth and their supporting bone in *Onychodus*. The present specimen seems to us to belong to a Teleostome, rather than a shark; and may have held a median, intermandibular position. This view finds some support in the fact that the teeth are striated, reminding one of Crossopterygian teeth. We propose the generic name *Atopacanthus* for this element (*atopos*, strange, odd, eccentric; *acantha*, spine, thorn).

The three elements referred to above as described by Hussakof in 1913 under the name *Apateacanthus peculiaris*, belong in the same genus, and should henceforth be known as *Atopacanthus peculiaris*.

Atopacanthus dentatus, n. gen., n. sp.

(Text-fig. 54, *A*)

E 2496 *Type.*—A fragmentary, narrow, compressed spine bearing three large teeth along one margin. Length, as far as preserved, 38 mm. (An additional 14 mm. is indicated by impression in the matrix.)

Formation and Locality.—Rhinestreet shale (Portage); forks of Eighteen Mile Creek, near Hamburg, N. Y. Collected by W. L. Bryant.

Body of spine, slender, bearing along one margin large, conical, compressed teeth, at right angles to the axis of the element. Undenticled margin not perfectly straight but with a few very slight convexities at short distances. Cross-section of element narrowly elliptical. Teeth relatively large, increasing progressively in size in the direction of the narrower end of the element; teeth with pulp cavity, and the outer face striated. Height of largest of the three teeth preserved in type specimen greater than width of element in region of this tooth. Teeth well separated but distance between adjacent teeth less than width of one of the teeth. Spine ornamented with a few longitudinal striations (mostly worn off in the type specimen).

Remarks.—This species is distinguishable at a glance from *Apateacanthus vetustus* (Clarke), by the fact that the teeth are vertical instead of inclined. From *A. peculiaris* (Hussakof) the present species differs in the teeth being narrower in proportion to their height, and in being strongly striated. It is possible, however, that in the latter species, perfect specimens showing the external surface of the teeth, not merely their impression, would also show the teeth to have been striated.

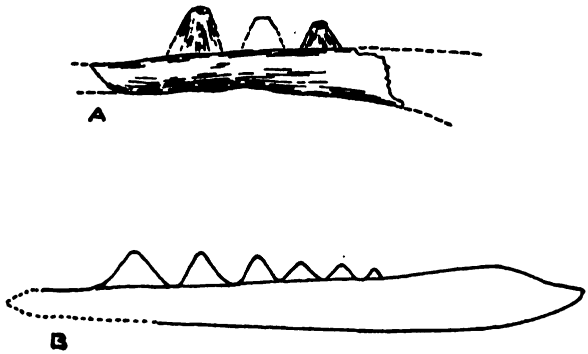

FIG. 54. **A,** *Atopacanthus dentatus*, n. gen., n. spec. TYPE, NATURAL SIZE. E 2496. **B,** *Atopacanthus peculiaris* (Hussakof.) FOR COMPARISON; REVERSED RIGHT TO LEFT.

Ctenacanthus nodocostatus, n. sp.

(Pl. 51, fig. 1)

E 2083 *Type.*—Impression in sandstone of a complete spine, 17 cm. in length.

Formation and Locality.—Yellow sandstone above "Second Mountain Sandstone" (Catskill); 4 miles South of Pleasantville, Venango County, Pa. Collected by J. F. Carll.

Spine of medium size, gently arcuate, with a large inserted portion, occupying about ¼ the entire length of the spine. Lateral faces ornamented with about 23 ridges, each composed of beads which are somewhat triangular in outline, with their apices directed downward, and generally, each apex covered by the base of the triangle below. The beading reduced or entirely absent from some ridges, particularly on the posterior half of the spine, where the ridges are almost smooth, and much finer than on the anterior part. Spaces between adjacent ridges, in middle part of spine, greater than width of a ridge. Line of demarcation between inserted and ornamented portions making an angle of 45 degrees with front margin of spine. Inserted portion with faint vertical striations and incisions. Posterior margin of each lateral face with a row of a small denticles directed somewhat downward.

Remarks.—This ctenacanth spine seems to be the first recorded from a Catskill horizon, if indeed the determination of the horizon in the old record be correct. The spine differs from all others by the peculiarities of the ornamentation referred to above, and may be recognized at a glance by the fact that the beading is absent entirely from some of the ridges and also from other spots on the spine, so that the smooth ridges and parts of ridges stand out clearly.

We have found one specimen with which the present one may be compared. This is the impression of the anterior half of a spine from the Hamilton, 1½ miles northeast of Pomeroy, Onondaga County, N. Y. (No. 874 Newb. Coll., Amer. Mus.) The specimen represents a spine considerably larger than the type. None the less, its style of ornamentation is so like that of the present species that we have no hesitation in referring it to it. *Ctenacanthus nodocostatus* therefore ranged from the Middle Devonic (Hamilton) to the top of the Devonic (Catskill). This imperfect specimen, in the Newberry collection, bears a label in Newberry's hand, reading *Ctenacanthus compressus* Newberry. It is obvious, however, on comparison of the specimen with the type of *C. compressus* and with another fine spine of the latter species, both in the Newberry collection, that the present spine is very different, and represents a distinct species. It appears probable that Newberry did not make a squeeze of the impression, but compared the impression directly, and this, superficially, resembles the ornamented face of *C. compressus*.

Ctenacanthus wrighti Newberry

(Pl. 52, fig. 2)

This species has hitherto been known only by the type specimen,[74] a large, well-preserved spine from the Hamilton (Mid. Devonic) of Yates County, N. Y. (No. 352 Newb. Coll., Amer. Mus.)

Several fragments of spines in the Buffalo Museum seem from their ornamentation to belong to this species. They are from the Conodont bed at Eighteen Mile Creek, N. Y., and were collected by W. L. Bryant. They thus extend the range of this species into the Genesee.

E 1904 Two fragments of spines with the ornamentation well preserved (Pl. 52, fig. 2). One of them agrees quite closely with the ornamentation of the type specimen.

E 2497 Fragment of a spine on a thin slab of rock together with numerous small fragments of Arthrodire plates, and several teeth.

Ctenacanthus sp.

E 2498 Fragment of a spine ornamented with rows of beads, each an elevated, transversely elongated tubercle with the upper margin smooth, somewhat beveled, the lower margin with strong pectinations; the whole bead resembling the form of a *Pecten* shell. This fragment probably represents a new species, but we do not wish to name it until a more or less complete spine, or at any rate a portion of a spine showing the size, form and number of ornamented ridges, is found.

Conodont bed (Genesee); Eighteen Mile Creek, near N. Evans, Erie County, N. Y. Collected by W. L. Bryant.

Cyrtacanthus dentatus? Newberry

(Text-fig. 55)

This species was based by Newberry on a spine of the kind now regarded as head spines, from their resemblance to the frontal claspers

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[74] *N. Y. State Mus., 35th Rep.*, 1884, p. 206, pl. xvi, figs. 12–14; *Paleoz. Fishes, N. A.*, p. 66, pl. xxvi, figs. 4, 4a, 4b.

of Chimæroids. The type specimen is preserved in the American Museum, and so far as known, it is the only specimen of the species ever discovered.

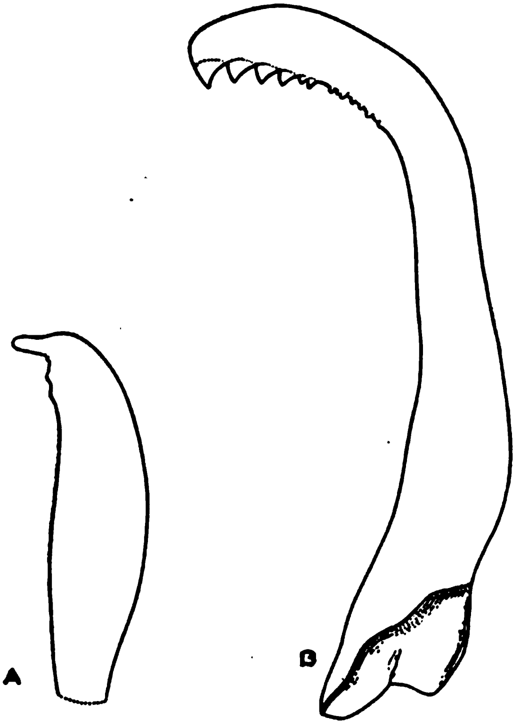

FIG. 55. **A,** *Cyrtacanthus?* Outline of Spine Labeled by Newberry: "*Cyrtacanthus dentatus?* N." Natural Size. E 1855

Onondaga limestone; Buffalo, N. Y.

55. **B,** *Cyrtacanthus dentatus* Newberry. Outline of the Type, Natural Size

Delaware limestone; Ohio. (Original in the Newberry Coll., Amer. Mus.)

E 1855 In the Buffalo Museum there is a portion of a spine (fig. 55, *A*) having some resemblance to the distal half of the type of *C. dentatus*. It was collected by Mr. F. K. Mixer, from the Onondaga limestone of Buffalo. The specimen was examined by Newberry, for it bears a label in his hand, reading, "*Cyrtacanthus dentatus? N. Cyrtacanthus* is probably one arm of a forked spine belonging to Agassiz's genus *Cladacanthus*." For comparison, an outline figure of the type of *Cyrtacanthus dentatus* (fig. 55, *B*) is given side by side with that of the present specimen.

The Buffalo specimen undoubtedly has a resemblance to Newberry's type, but it cannot be unreservedly regarded as of that species. The denticles on the incurved margin are absent, although one or two blunt protuberances suggest weathered denticles; and the outer surface near the distal extremity is not ornamented with tubercles as in the type. But on the whole the spine is more like the distal end of the type of *C. dentatus* than any other ichthyodorulite, and it is best to leave it in that species as was done by Newberry. Additional material illustrating the species is much to be desired.

As regards the affinities of *Cyrtacanthus:* it represents either a head spine, as stated above, or an unpaired spine placed in the median line of the fish. Newberry thought, as expressed in his note on the label of the Buffalo specimen, that *Cyrtacanchus* is probably one arm of the spine known as *Cladacanthus*. If we bear in mind that *Cladacanthus* is a synonym for *Erismacanthus*, this opinion is about all that one may express even at the present time; for *Cyrtacanthus* undoubtedly belongs in the group of head or median spines which includes *Erismacanthus*, *Harpacanthus* and allied forms.

Edestus minor Newberry

E 2153 Cast of a series of six teeth, attached to their supporting element.

Coal Measures: Indiana. (History of specimen unknown.)

Genus **Gamphacanthus** S. A. Miller[75]

Heteracanthus, J. S. NEWBERRY, Paleoz. Fishes N. Amer., 66, 1889, [preoccupied].
Gamphacanthus, S. A. MILLER, First Appendix [to N. Amer. Geol. and Pal.] 715, 1892.

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[75] In a paper published after the above was already in the hands of the printers, Eastman (*Proc. U. S. Nat. Mus.*, vol. 52, p. 244, 1917) employs the name *Heteracanthus* for *Gamphacanthus*. There seems to us no valid reason for doing so. *Heteracanthus* is clearly preoccupied. This was shown as long ago as 1892, by S. A. Miller, who proposed *Gamphacanthus* to replace it, which name was accepted by O. P. Hay in his *Bibl. and Cat. Fos. Vert. N. Amer.*, 1902 (p. 332). The fact that the relationship of these spines is at present unknown and they must be placed under the head of Ichthyodorulites, does not affect the matter of the name. If a generic name is applied it is amenable to the rule of priority.

We note also that Eastman refers these spines to Chimæroids—on the ground of their occurrence in the same formation with Ptyctodonts (which latter he considers to be Chimæroids). Unfortunately for this view, there are no fin-spines, nor indeed any skeletal or dermal elements similar to the *Gamphacanthus* spines in any Chimæroid.

This genus is known by two species, *G. politus* Newberry, and *G. uddeni* Lindahl, both from the American Devonic. The former ranges through the Hamilton and into the Portage; the latter is known only from the Hamilton. It is not clear to what group of fishes these spines pertain. The suggestion has been made by Eastman[76] that they may belong to Ptyctodonts, since they are frequently found in the same beds with ptyctodont and rhynchodont dental plates; however, beyond the fact of contemporaneity, there is no evidence for this view. Newberry[77] has remarked on the resemblance between these spines and those known as *Physonemus* and *Stethacanthus*.

Gamphacanthus uddeni (Lindahl)

(Pl. 52, fig. 1)

This species is represented by three specimens, one of them (E 1875) a nearly perfect spine (Pl. 52, fig. 1). This agrees closely with the type figured by Lindahl, except that it seems somewhat more compressed, a circumstance perhaps due to the mode of preservation.

There has been some vagueness about the distinctions between *Gamphacanthus uddeni* and the type species, *G. politus*. We have therefore compared two of the specimens of the former (E 1875 and E 1877) with the cotypes of *G. politus* Newb. (Amer. Mus. Coll.). *G. uddeni* as compared with *G. politus* is (1) more compressed, as shown by cross-sections of both the distal and proximal halves of the spine; (2) has a larger number of striations, especially in the proximal half; (3) the crenulations of the incised lines on the distal half are much less conspicuous and in some specimens entirely absent.

The three specimens in the Buffalo Museum are from the Hamilton (Mid. Devonic) of Milwaukee, Wis. Collected and presented by Mr. E. E. Teller, of Buffalo.

E 1875 Nearly complete spine, in matrix, (Pl. 52, fig. 1). Length, 112 mm.; greatest width (at 2 cm. from proximal margin), 33.

E 1876 Proximal half of spine, uncrushed and showing dimensions of pulp cavity.

E 1877 Proximal two-thirds of a spine somewhat larger than E 1875, in matrix. No sinuosities whatever are to be seen along

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[76] Devonian Fishes of Iowa. *Iowa Geol. Survey*, xviii, 139, 1908.
[77] *Paleozoic Fishes of North America*, 66, 1889.

the incised lines. This specimen confirms the impression derived from E 1875, that the species is somewhat more compressed than appears from Lindahl's figure of the type specimen.

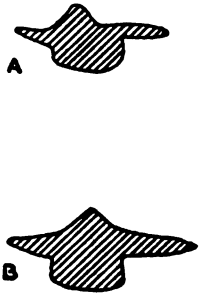

FIG. 56. CROSS-SECTIONS OF *Machæracanthus major*
A, section of distal third of spine; *B*, section at about middle.

Machæracanthus major Newberry

(Pl. 53, figs. 1, 2; text-fig. 56, *A*, *B*)

This genus persisted in western New York beyond the Mid Devonic, since it ranges into the Conodont bed (Genesee). It is represented in the collection by a number of specimens.

Specimens of Machæracanthus are always found with one side embedded in matrix, and as their knife-like lateral edges make it impossible to extricate them without damage, no specimen has to our knowledge ever been completely extricated from the matrix so as to allow of study from both sides. Furthermore, few specimens show the distal extremity in perfect preservation. One of our specimens, E 1848 (Pl. 53, fig. 2), consisting of the distal half of a large spine, shows this portion to be of rather different conformation than is usual in *M. major*, and it seems to us probable that the specimen represents the under side of the spine, whereas other specimens that have been figured represent the upper. This is of course only a supposition, which cannot be established unless a complete spine of *M. major* were extricated from the matrix, or one were sectioned at several levels, which, however, would destroy the spine as a specimen.

E 1847 Impression of an imperfect spine. Length, 140 mm.; greatest width, 25.

Onondaga limestone, (Mid. Devonic); Park Quarry, Buffalo, New York. Collected by Mr. F. K. Mixer.

E 1848 Distal half of a spine (Pl. 53, fig. 2). Length, as far as preserved, 95 mm.; greatest width, 21. This is the specimen referred to above as showing the opposite side to that already known in *Machæracanthus*. As will be seen from the figure, the median ridge, instead of extending to the point of the spine, terminates about 2 cm. from the extremity, at which point the ridge and the lateral alæ merge into a smooth, rounded surface. As this ridge is not sharp-angled, but broad and rounded, it is obviously the ridge on the opposite side to the one usually figured; and so gives for the first time information as to the form of the distal extremity of this side of the spine.

Onondaga limestone (Mid. Devonic); Cemetery Quarry, Buffalo, New York. Piper collection.

E 1849 Distal half of a spine. Length, as far as preserved, 92 mm.; width (at 55 mm. from apex), 21. This specimen agrees well with typical spines of this species. (Pl. 53, fig. 1.)

Onondaga limestone; Cemetery Quarry, Buffalo, New York. Collected by Mr. F. K. Mixer.

Machæracanthus longævus Eastman

Machæracanthus longævus Eastman, New York State Mus., Mem. x, 85, plate ii, fig. 8, 1907.

E 1874 *Type.*—Right and left pectoral fin-spines of one fish, imperfectly preserved; in counterpart.

Lower Hamilton (so-called "Trilobite bed"); shore of Lake Erie, near mouth of Eighteen Mile Creek, N. Y.

The original description of the specimen by Eastman,[78] may here be quoted.

> The present example is interesting in that it is one of the few in which spines of both pectoral fins are preserved in natural association. That this is the case, instead of there being merely a single, large broken spine, is evident from the similar proportions and general appearance of the two spines, one of which clearly represents the proximal and middle portions, and the other a section extending

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[78] Devonic fishes of the New York formations. *N. Y. State Mus., Mem. x*, 85–86. 1907.

from about the middle for a considerable distance beyond in the direction of the apex. The form of the cross-section leaves no doubt that both spines present the same aspect, presumably the outer or external face. On the opposite, or internal face, the median carina appears to be gently rounded throughout its entire length. One of the distinguishing characteristics of this species, however, is that the axial ridge on the side which is presumed to be external remains sharply triangular only in the distal half of the spine, becoming widened into a broad flat elevation, smooth or but faintly striated, and nearly rectangular in cross-section, toward the base of the spine. The general surface is smooth, save for the usual delicate striæ, slightly convergent toward the apex, and possibly of the same nature as growth lines.

The foregoing description is, however, incorrect in one particular. The spines do not both present the same aspect. It is plain from the conformation of the median ridges and from the curvature of the two spines as they appear side by side, that one presents the inner, and the other the outer aspect. The median ridge of one is triangular in cross-section, while in the other it is flat.

The following specimen from the Conodont bed apparently also belongs to this species. If the determination is correct it extends the range of the species from the Lower Hamilton (Mid. Devonic) into the Lower Genesee (U. Devonic).

E 1906 Fragment of a spine having a cross-section somewhat similar to that of *M. longævus*.

Machæracanthus peracutus Newberry

(Pl. 53, fig. 3)

The following specimens, which are smaller and more slender than examples of *M. major* probably belong to *M. peracutus* Newberry.

E 1850 Distal half of spine, in matrix. (Pl. 53, fig. 3).
Onondaga limestone; Cemetery Quarry, Buffalo, New York. Collected by Mr. F. K. Mixer.

E 1851 Incomplete spine.
Onondaga limestone; Cement Quarry, Buffalo, New York. Collected by Mr. F. K. Mixer.

E 1852 Spine of a young individual. In the smaller spines of this species, the longitudinal axis of what we here call the under side, is relatively higher than in those of adults. Other data same as preceding.

E 1853 Fragment of a spine.
Onondaga limestone; Park Quarry, Buffalo, New York. Collected by Mr. F. K. Mixer.

E 1854 Fragment of a spine.
Onondaga limestone; Cement Quarry, Buffalo, New York. Piper collection.

Machæracanthus sp.

(Pl. 53, fig. 4)

In addition to the specifically determinable spines described above, there are in the Buffalo Museum a number of spine fragments collected by Mr. Bryant in the Conodont bed, which are rather more slender than is usual in spines of this genus. They are most like those of *M. peracutus*, but may represent a distinct species.

E 2514 Distal third of a spine drawn out to a much more slender point than in any species of *Machæracanthus* of which the complete spine is known; in matrix (Pl. 53, fig. 4). Length, as far as preserved, 57 mm.; greatest width, 13. The spine possibly appears so slender through the thin lateral alæ having been broken away before the specimen became embedded in sediment.

E 2515 Distal end of a spine; the lateral alæ restored in plaster.

Onchus rectus Eastman

E 2591 Spine measuring 3.5 cm. as far as preserved. The distal extremity is lacking and the proximal half of the inserted portion is represented only by the impression. The spine when complete measured not more than 4.5 cm. It agrees in every character with Eastman's description of this rare species, hitherto known only by two specimens from the Chemung of Delaware County, N. Y.

Limestone layer at the horizon of the "Third oil sand" (Chemung group), Erie, Pa. Collected by Mr. E. J. Armstrong.

Stethacanthus præcursor, n. sp.

(Pl. 54, figs. 1, 1a, 2)

E 1908 *Cotypes.*—Two nearly complete spines.

(1) The more perfect specimen of the two; length, 82 mm. (Pl. 54, fig. 2). It shows the apex of the spine, the hump (somewhat injured) and the region behind it.

E 1909 (2) This spine lacks the apex, and the two faces are crushed together in the hump region; but it shows the inferior margin of the front half of the spine. Length, as far as preserved, 78 mm.

Formation and Locality.—Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Spine about 9 cm. in length; depth at beginning of hump contained about 3 times, and the part of spine behind hump about 3½ times, in the total length. Hump in profile view, gently convex above, and descending to meet the post-hump portion of spine in a slight sigmoid curve; hump, viewed from above, relatively broad (its posterior margin is not sufficiently preserved to show its entire outline); its height less than the portion of the spine back of it. Upper margin of spine gently concave, changing to gently convex toward the apex; "lower" margin of apex almost straight. Sides of spine incised with short, irregular lines and shallow grooves more or less parallel to the axis of spine.

Remark.—This species is known only by the two cotypes. These are complete spines, but not well-preserved; between the two, however, the characters of the species may be fully made out. Plate 54, figure 1, is a composite drawing based on the two specimens.

The species is readily distinguished by the relatively straight apical portion, which is not reflexed upward as in most species (for instance, *S. altonensis*); and by the form of the hump, as well as its relative size as compared with the post-hump portion of the spine.

If we compare the present species with *Stethacanthus* spines from later horizons, we are perhaps justified in regarding it as primitive or generalized. This is shown by the fact that the apical portion of the spine is straight, not recurved; in later forms this portion is gently reflexed upward so as to produce a deep excavation between hump and apex. In fact, in some of the later spines, for instance, the small species *S. erectus* Eastman, and *S. exilis* Hussakof, both from the Waverly, this is carried to an extreme, the apical axis being at right angles to the hump.

Stethacanthus depressus (St. John & Worthen)

(Pl. 54, fig. 3)

E 2516 Impression of a small spine in sandstone; also a squeeze of same in dental wax.

The specimen, though small, is complete and shows well the characters of the species.[79] Length 30 mm. (apex missing); height at posterior border of hump, 8 mm.

Top layer of "Second Mountain Sandstone" (Catskill); Crawford County, Pa. Carll collection.

Ichthyodorulite, indet.

E 1907 A thin, fragmentary spine, or plate, with serrated edges, and a rounded central axis which gives it somewhat the appearance of a fragment of a *Machæracanthus* spine. Perhaps an Arthrodire plate.

DIPNEUSTI

Dipterus gemmatus, n. sp.

(Pl. 56, figs. 2, 2a)

E 2517 *Type.*—A small dental plate on a piece of limestone.

Formation and Locality.—Conodont bed (Genesee); Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Dental plate small, about 13 mm. in length (antero-posterior diameter), its greatest width about two-thirds its length. Ridges, five or six, tuberculated, radiating from a smooth central area which

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[79] The specimen figured by Eastman in *Bull. Mus. Compar. Zool.*, xxxix, 216, fig. 15, as *Stethacanthus depressus*, is incorrectly referred to this species.

occupies over one-third the length of the plate (at the middle ridge). Outermost denticles of each ridge rounded, succeeding ones somewhat compressed, and in the principal ridge tending to fuse into a compressed edge. Number of denticles in principal ridge, two or three; in second ridge, three; in third, four; in fourth, five. In the third and succeeding ridges the outermost denticles are more or less discrete, i. e., not confluent at their bases. All denticles, as well as interspaces between them, covered with minute punctæ.

Remarks.—This species is closest to *Dipterus flabelliformis* Newberry, and *D. pectinatus* Eastman. It is distinguished by the much larger smooth, central area; by having fewer ridges, and in each ridge fewer and more discrete denticles. In the third longest ridge of *D. flabelliformis* there are nine or ten denticles, whereas in the third ridge of the present species there are only four.

Dipterus valenciennesi Sedg. & Murchison

E 2518 A fine head-shield, 5 cm. in length, showing prettily all the head plates and the sensory canals.
Old Red Sandstone; Weydate, Thurso, Scotland.

Dipterus nelsoni (Newberry)

E 2519 Right mandibular dental plate. Chemung conglomerate? N. W. Pa. Collected by J. F. Carll.

Dipterus sp.

E 2015 A small dental plate, in matrix (Pl. 56, fig. 1). Conodont bed; Eighteen Mile Creek, near North Evans, Erie County, N. Y. Collected by W. L. Bryant.

Scaumenacia curta (Whiteaves)

(Pl. 57, figs. 3, 4; text-fig. 57)

This is now one of the best known of Devonian lungfishes, the exquisitely preserved specimens found in the Scaumenaç Bay region of Canada having afforded a knowledge of every detail of its external structure. A restoration of this form has been published by Hussakof[80] (text-fig. 57).

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[80] Hussakof, L.: Notes on Devonic fishes from Scaumenac Bay. *N. Y. State Museum, Bull. 150*, p. 135, 1912.

In the Buffalo Museum there are a number of fine specimens of this species, collected by Mr. Bryant at the type locality, the Upper Devonian shales on Scaumenac Bay, near the village of Megouasha, Quebec, in August, 1915.

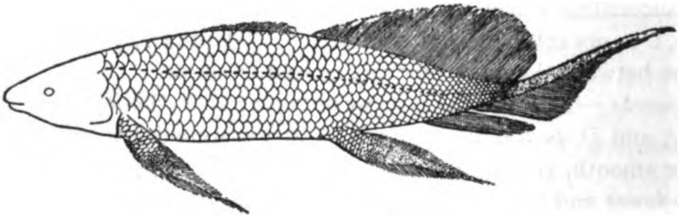

FIG. 57. RESTORATION OF *Scaumenacia curta* (Whiteaves). UPPER DEVONIC SCAUMENAC BAY, QUEBEC. AFTER HUSSAKOF.

E 2521 A small fish, 15 cm. in length, shown in side view. It exhibits the head and all the fins. The head is imperfectly preserved but shows beautifully the posterior half, represented by the impression of the upper surface. The palatines are moved from their natural position, but show in oral view. The most interesting thing about the specimen is that the entire upper dentition, consisting of both dipterine as well as both vomerine plates, is preserved. The dipterine plates are broken but agree in their general characters with the description of these plates given by other authors. The vomerines are stout, and somewhat compressed. One, which is perfectly preserved, has two cusps or serrations; the other, two and the "root" of a third. Each cusp is sculptured by a broad, shallow furrow on the outer face. (Pl. 57, fig. 3.)

The discovery of a specimen of *Scaumenacia* showing the vomerine teeth is of very great interest. Another such specimen was described by Hussakof in 1912;[81] and in the same year Dr. William Patten[82] published restorations of *Scaumenacia* in which so-called premaxillaries are indicated. Watson and Day[83] have suggested that

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[81] Hussakof, L.: Notes on Devonic fishes from Scaumenac Bay, Quebec; *N. Y. State Mus. Bull. 158*, pp. 127, 139; 3 plates, 1912.

[82] Patten, W.: The Evolution of the vertebrates and their kin. Philadelphia. P. 386, fig. 261–F; p. 389, fig. 264, 1912.

[83] Watson, D. M. S. and Day, Henry: Notes on some Palæozoic fishes. *Mem. & Proc. Manchester Lit. & Phil. Soc.*, lx, p. 33, 1916.

the teeth figured by Hussakof might represent the premaxillaries. However, the specimen found by Mr. Bryant seems to indicate that these teeth are true vomerines.

In the specimen previously described, the vomerines had respectively four and five cusps. In the present one there are two and three. This indicates that the number of cusps or serrations was not constant, but varied in different individuals, and probably also with age. "In view of this serrated condition the vomerines of *Scaumenacia* may be regarded as more primitive than those of the adult *Neoceratodus*. They resemble somewhat the vomerines of the embryonic *Neoceratodus* as described by Semon."[84] (Hussakof, *loc. cit.*, page 137.)

E 2520 A large fish lacking the head, but showing all the fins and the lateral line in great perfection. The body is not so distorted as in most small specimens of this species. In the same matrix is the impression of a dorsal shield of *Bothriolepis*.

E 2522 Crushed head, shown from above, and displaying dentition.

E 2523 Small fish lacking head; in counterpart. It shows nearly a complete series of neural and haemal spines, the cleithrum and other details. Length 10.5 cm.

E 2524 Fish, in counterpart, showing the head; dorsal, caudal and anal fins; also the eye, jaws, scale ornamentation, calcified neural and haemal spines, and fin supports. Length 11 cm.

E 2525 Small fish, showing both dorsals, the anal and caudal fins also haemal spines and the lateral line. Length 11.5 cm.

E 2526 Fish lacking head, but showing both dorsals, the anal and part of the caudal. Length 12 cm.

E 2527 Fish, in counterpart, showing the second dorsal, caudal, and anal fins; also the cleithrum, and the lateral line. Head crushed. Length 16.5 cm.

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[84] Semon, R.: Die Zahnentwickelung des *Ceratodus forsteri*. *Zool. Forsch. in Austral. u. Malay Archipel.*, 115–135, pl. xviii–xx, 1899.

E 2528 Small fish, showing lateral line, cleithrum and other details Length 9 cm.

Dipnoan Scale

E 2545 A large punctate scale, 4.5 by 3.5 cm. (broken), perhaps belonging to a dipnoan.

Catskill; Seeley Creek, branch of Lambs Creek, near Mansfield, Tioga County, Pa. Collected by W. L. Bryant, 1913.

[The type of *Dipterus sherwoodi* was found in this locality.]

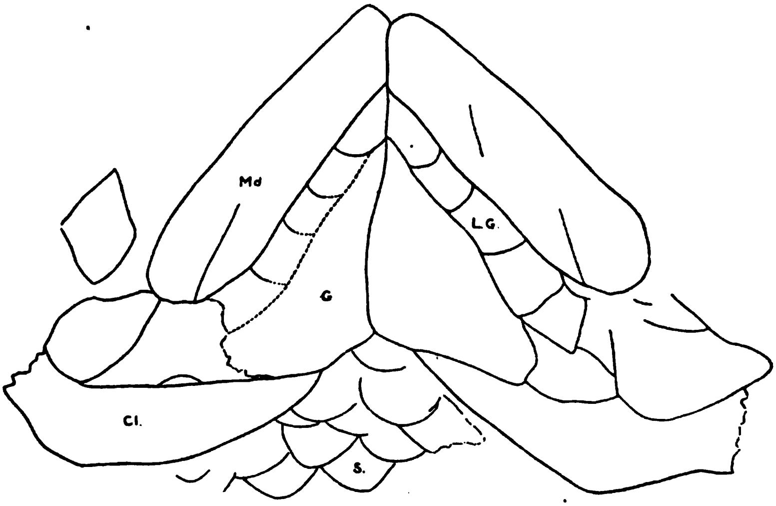

FIG. 58. *Holoptychius quebecensis* (Whiteaves). GULAR REGION. × ABOUT ⅓ *Cl*, cleithrum; *G*, gular; *L.G*, series of lateral gulars; *Md*, mandible; *S*, scales. E 2529.

CROSSOPTERYGII

Family HOLOPTYCHIIDÆ

Holoptychius quebecensis (Whiteaves)

(Text-fig. 58)

This species is still imperfectly known, owing to the fact that specimens of it are usually much broken or fragmentary. In the Buffalo Museum there are two specimens that show the throat region with the principal and lateral gulars in position. This part of the anatomy is of course known in other species of the genus, e.g., from the Old Red Sandstone of Scotland.

E 2529 Gular region of a large fish (fig. 58). It shows the principal and lateral gulars very prettily, and on the outside of these, the mandibles. Most of the bone is gone but the impressions of the plates are clearly indicated. The lower parts of both cleithra are preserved. Between their extremities and back of the principal gulars are a number of imbricating scales. Preserved fragments of the bone of both the principal and the lateral gulars, show that these plates were ornamented with small, crowded tubercles which were not coalesced into lines. The scales immediately back of the gulars are for the most part ornamented with tubercles, which in some scales are more or less coalesced into lines.

Upper Devonic; Scaumenac Bay, near Village of Megouasha, Quebec. Collected by W. L. Bryant. August, 1915.

E 2530 Gular region of a smaller fish than the preceding. Both the principal and lateral gulars are shown, the bone being present and viewed from the inner or visceral aspect. The arrangement is very similar to that of the preceding specimen. There are five or more lateral gulars on either side.

Holoptychius americanus Leidy

E 2151 Cast of a large scale.

Chemung; Tioga County, Pa.

E 2544 Impression of scales.

Catskill; Seeley Creek, branch of Lambs Creek, Mansfield, Tioga County, Pa.; collected by W. L. Bryant.

Holoptychius giganteus Agassiz

E 2531 Scales, fin-rays and a head plate (?). Length of scale 22 mm.; width, 25 mm.

Other data same as preceding.

Holoptychius halli Newberry

E 2532 Impression of a scale; length, 2 cm.; width, 1–5 cm. Catskill ? Northern Pennsylvania—exact locality unknown; collected by J. F. Carll. [The type of the species comes from the Catskill at Delhi, N. Y.]

Holoptychius cf. **nobilissimus** Agassiz

E 2533 Cast of a scale. Length, 55 mm.; width, 45 mm. (broken). It has the reticulated ornament of *H. nobilissimus*, but was apparently as large as *H. giganteus*. Original in Philadelphia Acad. of Nat. Sci.

Mansfield ore bed (Upper Chemung); Tioga County, Pa.

Holoptychius serrulatus ? Cope

E 2534 Impression of a scale and fin-rays. (Compare Smith Woodward, *Cat. Fos. Fishes Brit. Mus.*, II, pl. xi, figs. 1c, 1d; Cope, *Proc. Am. Phil. Soc.*, vol. 36, pl. ii, fig. 1.[85]

The tubercles of the covered area seem to be completely fused into ridges. Resembles *H. serrulatus* Cope, but is smaller and lacks the cone-like tubercles of the covered portion. It may, however, be a caudal scale of this species as it came from the same formation and locality as *H. serrulatus* Cope.

Catskill; Seeley Creek, branch of Lambs Creek, Mansfield, Tioga County, Pa.; collected by W. L. Bryant.

Family RHIZODONTIDÆ

Eusthenopteron foordi Whiteaves

(Pl. 70, fig. 2)

Of this well-known species there are a number of excellent specimens in the Buffalo Museum, collected at the type locality, the Upper Devonic of Scaumenac Bay, Quebec, by Mr. W. L. Bryant, in August, 1915.

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[85] The figures in this paper are wrongly numbered: Figure 1 is *H. serrulatus*: Figure 2, *H. flabellatus*: Figure 3, *H. latus*.

E 2535	Head of a large fish, little crushed, and showing clearly the plates of the roof and the right side of the cranium, including the mandible and gular plates; eye and lateral lines well shown. In addition to these features, the fossil shows portion of a pectoral fin with its supports and the ornamented squamation of the fore part of the trunk. Length, 16 cm.
E 2536	Complete fish with all fins. The head is bent backward upon the body, showing its inferior aspect.
E 2537	Posterior half of fish showing anal, second dorsal and caudal fins.
E 2538	Fish, in counterpart, showing dentition. Fins imperfectly preserved.
E 2539	Crushed head of small fish, showing gular plate, jaws and roofing bones, in inner view.
E 2540	Tail of a large fish.
E 2541	Fish lacking head but showing outline of body, all fins, lateral line and operculum.
E 2546	Fragments. Anterior portion of fish with a few head plates and the pectoral fin.
E 2547	Fragment of cranium, showing supratemporal bones from the inside.
E 2548	Portion of trunk of fish, showing vertebral centra.
E 2549	Pair of mandibles of a small fish. The laniary teeth are shown, some of them fractured, affording a longitudinal view of the pulp cavity.
E 2550	Scales of trunk.
E 2551	Weathered specimen showing disarticulated head plates and jaws.
E 2552	Posterior half of a very young fish, showing outlines of body, both dorsals, the ventral, anal, and caudal fins; in counterpart.

E 2553 Fragmentary head of large individual, in counterpart, showing mandible, maxilla, suborbital and the gular plates.

E 2554 Nearly complete fish so twisted as to show lateral view of trunk and tail, and inner aspect of cranium; the sutures of the cranium have opened so as to show the outlines of the component plates. Body is somewhat macerated, but the pectoral, ventral and caudal fins are preserved.

E 2555 Side and top view of a crushed cranium, together with a fragment of the pectoral fin. Roofing bones and jaws well shown.

E 2594 Pectoral region of large fish, showing squamation, and an excellently preserved pectoral fin with its supports (Pl. 70, fig. 2).

Family ONYCHODONTIDÆ

Genus **Onychodus** Newberry

A genus of Crossopterygii known only by detached head plates, jaw elements, teeth and scales. Its most remarkable feature is the presymphyseal bone with its semicircle of teeth. Three American species have been described, all from the Devonic; but of these two seem to be synonymous—*O. sigmoides* and *O. hopkinsi.* The latter was based on somewhat smaller and less curved teeth than *O. sigmoides,* but the materials now in various museums show that some teeth from the *hopkinsi* locality are fully as large and as much curved as any *sigmoides* teeth.

Onychodus sigmoides Newberry[86]

(Pl. 58; text-fig. 59)

Onychodus sigmoides NEWBERRY, Proc. Nat. Inst., n. ser. 1; 124, 1857.
Onychodus hopkinsi NEWBERRY, Ibid., 124, 1857.

This species is represented in the collection by a number of plates and teeth. Of special interest are the remains from the Conodont

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[86] For full synonymy see Hay, *Bibliography and Catalog Fossil Vert. N. A.*, 1902, p. 363.

bed, at Eighteen Mile Creek, for they demonstrate that this typically Onondagan species ranged into the Genesee. This is not surprising, since remains of *Onychodus* have been recorded from the Chemung. The surprising thing is—if all these remains really belong to a single species—that *Onychodus sigmoides* should be represented both in fresh (Chemung) and in salt water (Conodont and Onondaga limestone).

The mandible of *Onychodus* described below is of unusual interest, since it affords for the first time a knowledge of the structure of this element in the genus. The specimen (Pl. 58, fig. 3 and text-fig. 59) consists of about two-thirds of a left mandible; it lacks the anterior, or symphyseal end, as well as the posterior extremity. The upper margin is set with slender, sharply-pointed laniary teeth placed at wide intervals, and not all of the same size. Some of them had apparently become worn through use, or else had been broken off before preservation. The mandible clearly indicates the presence of several distinct elements; first, a dentary element (*den.*), a narrow element in which the teeth are set, extending the entire length of the preserved portion of the mandible. Second, an angular (*ang.*), situated below the dentary, and extending forward about two-thirds the length of the mandible. Third, an articular element (*art.*); the bone itself is absent in the specimen, but its position is clearly indicated by the sutural lines and facets on the angular and dentary. It was wedged in anteriorly between these two elements.

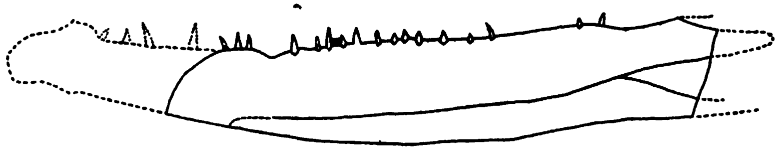

FIG. 59. *Onychodus sigmoides* Newberry. RESTORED OUTLINE OF MANDIBLE SHOWN IN Plate 58, FIGURE 3

All the elements composing it are shown—the *dentary* above, *angular* below, and the *articular*, at the extreme right, wedged in between these two. The front end of the mandible is restored after a specimen from the Delaware limestone of Ohio. Onondaga Limestone; Leroy, N. Y. E 2556.

It has been customary in describing the mandibles of the *Crossopterygii*, to refer to all the elements below the dentary, as *infradentaries*, except the most posterior one, which has generally been called *angular*.[87] But the demonstration in recent years that the *Crossopterygii* are ancestral to the Tetrapoda, necessarily changed this point of view, and the Crossopterygian mandible is now regarded as possessing elements homologous with those of primitive amphibia. This conclusion rests on the cumulative work of Smith Woodward, Broom, Williston, Gregory and Watson. Broom[88] in a special paper on the subject, in 1913, showed that in the mandible of the Crossopterygian *Sauripterus taylori*, from the Chemung of Pennsylvania, the infradentaries represent the elements found in the typical Stegocephalian mandible, for instance, *Trimerorachis*, and that they may be interpreted as splenial, preangular, angular, surangular, prearticular and articular. So, too, in the latest paper on the subject, by W. K. Gregory,[89] this is the view advocated. And it is in line with this newer interpretation that the elements in the mandible of *Onychodus* are named above. Our specimen does not show the front portion of the mandible, so that the splenial, if present in *Onychodus*, is not shown. And at the posterior end, the surangular is not preserved.

1. Specimens from the Delaware limestone (Mid. Devonic); Delaware, Ohio.

E 1871 A series of six premandibular teeth with their supporting symphyseal bone. The teeth are curved, as is usual in these specimens (Pl. 58, fig. 2).

E 1872 A series of symphyseal teeth, and their supporting bone. One tooth shifted from its position.

This and the following specimen were presented by Mr. E. E. Teller.

E 1873 A detached tooth, 4 cm. in height. (Pl. 58, fig. 1)

2. Specimens from the Onondaga limestone at Leroy, N. Y.

E 2556 The fine mandible discussed in the preceding pages and illustrated in Plate 58, figures 3, 3a, 3b, and text-fig. 59.

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[87] See for instance the excellent figure of the mandible of *Rhizodus hibberti* in Smith Woodward's *Catalog of Fossil Fishes*, Part II, pl. xii, fig. 1.

[88] Broom, R.: On the structure of the mandible of Stegocephalia *Anat. Anz.*, xlv, 77–78.

[89] Gregory, W. K.: Present status of the problem of the origin of the Tetrapoda with special reference to the skull and paired limbs. *Annals N. Y. Acad. Sci.*, xxvi, 317–383, pl. iv, 1915. See especially p. 334 for table of homologies between bones of mandible in Rhipidistia and Stegocephali, and for references to the work of Smith Woodward, Williston, Broom, and Watson, on which these conclusions rest.

It is rather small and is apparently not of a full-grown fish.

Collected and presented by Prof. Clifton J. Sarle.

E 2564 A large tooth, 30 mm. in height (imperfect).

Collected and presented by Prof. Clifton J. Sarle.

3. Specimens from the Conodont bed (basal Genesee) at Eighteen Mile Creek, near N. Evans, Erie County, N. Y.

E 2557 An imperfect presymphyseal tooth, in matrix, shown in longitudinal section. The tooth is 43 mm. in height, and the pulp cavity extends to within 6 mm. of the tip. The wall of the tooth is slightly over 1.5 mm. in thickness

E 2563 A mandibular tooth, 40 mm. high.

Family CŒLACANTHIDÆ

Cœlacanthus elegans Newberry

E 2090 Imperfect fish on coal.

Coal Measures; Linton (now Yellow Creek), Jefferson County, Ohio.

Presented by J. S. Newberry.

E 2091 Caudal extremity of a fish on coal.

Other data same as preceding.

ACTINOPTERYGII

Family PALÆONISCIDÆ

Cheirolepis canadensis Whiteaves

(Pl. 57, figs. 1, 2)

E 2558 Tail, showing ornamented scales and fin-rays

Upper Devonic; Scaumenac Bay, near village of Megouasha, Quebec. Collected by W. L. Bryant, August, 1915.

Genus **Rhadinichthys** Traquair

In the Portage rocks in the vicinity of Buffalo occur scales, cranial plates and incomplete fishes, which apparently belong in the palæoniscid genus, *Rhadinichthys.* They have been described as three distinct species:

1. *Rhadinichthys devonicus.*—J. M. Clarke; Bull. 16, U. S. Geol. Surv., p. 41, Plate i, figures 2–6, [as *Palæoniscum*]. 1885.
2. *Rhadinichthys antiquus.*—H. U. Williams; Bull. Buffalo Soc. Nat. Sci., v, p. 84, figure 2. [as *Palæoniscum*]. 1886.
3. *Rhadinichthys reticulatus.*—H. U. Williams; Ibid., p. 86, figure 1. 1886.

Of these three names the last seems to be a synonym of the first; so that only two species may properly be recognized, distinguished from each other by details of ornamentation of the scales and cranial plates.

Rhadinichthys devonicus (Clarke)

(Pls. 59, 60, 61, 62; 63, figs. 1, 2; 65; text-figs. 60, 61)

In 1885 John M. Clarke described an imperfect fish and a number of isolated scales and cranial plates under the name of *Palæoniscum devonicum.* The specimens were collected in a "railroad cutting through the bituminous layers in the town of Sparta"—a Portage horizon. In the following year H. U. Williams described and figured a number of isolated scales and cranial elements from the Portage near Buffalo, which he placed in two new species, *Palæoniscum reticulatus* and *P. antiquus.* It seems to us on careful comparison of his figures of *P. reticulatus* with the figures and description given by Clarke of *P. devonicus,* that these names refer to the same species.

The following is Dr. Clarke's account of this species:

> One individual retains most of the body in place, though the bones of the head have been displaced and scattered, and the tail is somewhat crushed. The animal was originally about 13 cm. in length. The cranial bones, ... are characteristically marked by punctate incised lines which run along the greatest diameter of the bone, occasionally [as in his figure 5] radiating from the most convex portion of the plate. . . . . Associated with these bones are many minute, shining, somewhat flattened, conical teeth, measuring 0.75 mm. in length. The scales, except those on the dorsal ridge, are 1.5 mm. long and 5 mm. wide, subrhomboidal in outline and very beautifully sculptured with strong elevated striæ, which take their origin at the upper forward angle and pass obliquely across the scale, the forward edge presenting the appearance of being strongly tucked. These elevated striæ become very much stronger at the posterior edge, and in this region, the upper portion of the scale being left free of striæ, shows strong punctate markings. These pittings are also to be seen in the furrows between the striæ on the anterior portions of the scale.

The median dorsal scales are large, spatulate in form, measuring 3.5 mm. in width anteriorly, and narrowing backwards to 1.5 mm.; length 4 mm. Surface strongly punctate.—J. M. Clark, "On the higher Devonian faunas of Ontario County, New York, *Bull. 16, U. S. Geol. Surv.*, 1885, p. 41.

If we compare the figures given by Clarke and by Williams (the latter reproduced here as fig. 60), we find a very close correspondence. Thus, Williams' figure 1*d*, might almost have been drawn from the cleithrum of *Palæoniscus devonicus*, figured (as a cranial plate) by Clarke in his Plate i, figure 5; while Williams' figure 1*c*, of a cranial plate, agrees fairly well with Clarke's figure 6. Both these latter show a cranial plate ornamented with more or less parallel lines anastomosing in places. Williams' figure of the scales, 1*a*, agrees with Clarke's figure 3, except that in Clarke's figure the punctæ are not so clearly shown.

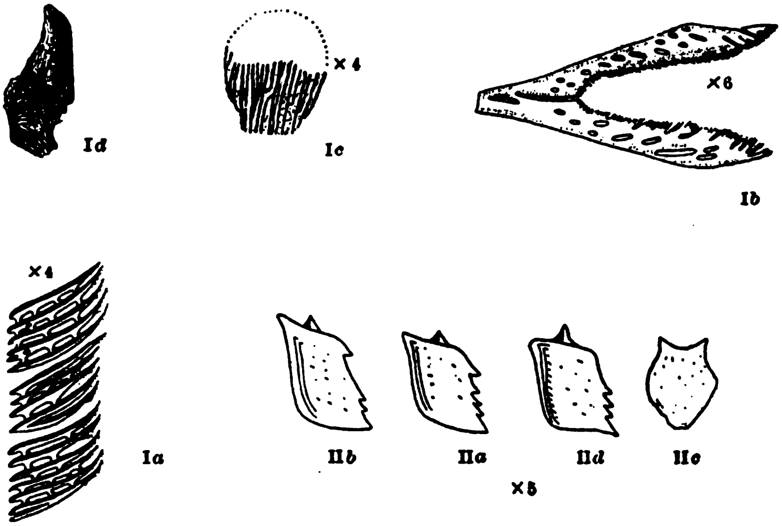

FIG. 60. BONES AND SCALES OF *Rhadinichthys*, ENLARGED. (AFTER H. U. WILLIAMS)

I *a–d*, *Rhadinichthys devonicus* (Clarke). I *a*, flank scales; I *b*, fulcral scale; I *c*, fragment of bone showing ornamentation of reticulated lines; I *d*, cranial plate showing ornamentation.

II *a–d*, *Rhadinichthys antiquus* (Williams). II *a*, *b*, *d*, flank scales, showing peg for articulation; II *c*, ridge scale.

It thus seems to us that the forms described by Clarke and by Williams from isolated scales and plates, represent a single species; and for this Clarke's specific name, *devonicus*, has priority.

This species is represented in the Buffalo museum by a considerable series of scales, cranial plates, fulcra, etc., preserved singly or in groups, on small pieces of shale. All are from the Rhinestreet shale (Portage), on the shore of Lake Erie, near Sturgeon Point, N. Y.

E 2044 Imperfect fish, showing outline of body and caudal extremity (Pl. 59). This and the following five numbers collected by Mr. F. K. Mixer.

E 2045 Cranial plates including the frontal and the operculum; detached scales and a number of elongated fin-rays. Some of the plates show the sensory canals (Pl. 60, fig. 3).

E 2046 Parietal? plate.

E 2047 Operculum. (Pl. 60, fig. 2; text-fig. 61, B.)

E 2048 Left cleithrum. (Pl. 60, fig. 1; text-fig. 61, A.)

E 2049 Cranial plates, scales and fin-rays of a single individual. (Pl. 62, fig. 4; Pl. 63, figs. 1, 2.)

E 2050 Right maxilla. (Pl. 61, fig. 3.) This and the following specimens collected by Mr. W. L. Bryant.

E 2051 Right maxilla. (Pl. 61, fig. 1.)

E 2052 Right maxilla.

E 2054 Left maxilla.

E 2053 Right cleithrum.

E 2055 Left mandible. (Pl. 62, fig. 1.)

E 2056 Mandible showing teeth in two series.

E 2057 Mandible? lacking teeth.

E 2058 Mandible, lacking teeth.

E 2059 Mandible, lacking teeth.

E 2060 Mandible, lacking teeth.

E 2061 Detached scales. (Pl. 62, figs. 2, 3.)

E 2062 Cranium, shown in inner view.

E 2063 Cranial plate (post-temporal?), shown in inner view.

E 2064 Supraclavicle?

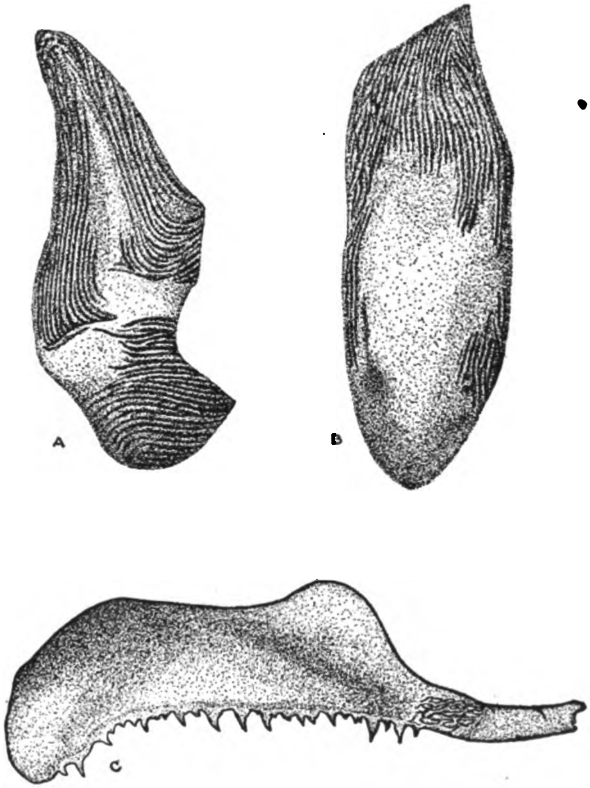

FIG. 61. *Rhadinichthys devonicus* (Clarke). × 3

A, cleithrum; E 2048. Drawn from specimen shown in Plate 60, figure 1. **B,** operculum; E 2047. Drawn from specimen shown in Plate 60, figure 2. **C,** right maxilla, outer view, but with almost entire surface ornament lost; E 2067. Plate 61, figure 2.

E 2066 Right maxilla, with teeth. (Pl. 65, fig. 2.)

E 2067 Right maxilla, with teeth. (Pl. 61, fig. 2; text-fig. 61, C.)
F. K. Mixer, coll.

Rhadinichthys devonicus? (Clarke)

(Pl. 65, figs. 1, 3)

Several isolated plates in the collection, from the Cleveland shales of Ohio, bear an ornamentation very similar to that of plates of *Rhadinichthys devonicus* from the Portage of Western New York, and it appears probable that they belong to the same species. They are of about the same size as the latter, and so far as can be made out from their imperfect preservation, they have the same outlines as the corresponding plates of the Western New York form. In Plate 65, figure 1, a maxilla from the Cleveland shale is shown, for comparison, near a maxilla of *Rhadinichthys devonicus* (E 2066) from the Portage near Buffalo.

E 2565 A right maxilla, on a piece of shale, displaying ornamentation and greater part of outline of the element. (Pl. 65, fig. 1).

Cleveland shale (Upper Devonic); Linndale, near Cleveland, Ohio. Collected by W. L. Bryant.

E 2566 Both mandibles, separated from each other, and displaying the outer, ornamented surface. Teeth are to be seen in both mandibles, but cannot be clearly made out. (Pl. 65, fig. 3.)

Other data same as preceding.

Rhadinichthys antiquus (Williams)

(Pl. 63, fig. 3; Pl. 64; text-fig. 62)

The following specimens in the collection are all from the Rhinestreet shale (Portage), on the shore of Lake Erie, near Sturgeon Point, N. Y.

E 2065 Imperfect fish, showing head, trunk and caudal fin; the dorsal, anal, and paired fins are missing. (Pl. 63, fig. 3; text-fig. 62.) Collected by Mr. F. K. Mixer.

E 2068 Left cleithrum. (Pl. 64, fig. 1.) This and the following specimens collected by Mr. W. L. Bryant.

E 2069 Left cleithrum.

E 2070 Imperfect left cleithrum.

E 2071	Impression of right cleithrum.
E 2072	Cranial plate.
E 2073	Detached scales.
E 2074	Detached scales. (Pl. 64, figs. 2, 4, 5, 6.)
E 2075	Detached scales.

FIG. 62. *Rhadinichthys antiquus* (Williams). POSTERIOR HALF OF FISH, SHOWING HETEROCERCAL TAIL, AND THE FULCRA OF ITS UPPER AND LOWER LOBES. NATURAL SIZE. E 2065

Rhadinichtys ? indet.

E 2076–7 That another species of Palæoniscid in addition to tne two preceding inhabited the waters of what is now Western New York during Portage time, is indicated by two specimens in the collection—a cleithrum and a cranial plate, whose external faces are ornamented by a series of crenulated ridges, arranged transversely to the long diameter of the bone.

Rhinestreet shale (Portage); shore of Lake Erie, near Sturgeon Point, Erie County, N. Y. Collected by W. L. Bryant.

Rhadinichthys alberti (Jackson)

(Text-fig. 63)

This is the best known American species of *Rhadinichthys*, and extensively represented in museums. For a full account of it, with a restoration and admirable figures of scale detail, reference should be made to the memoir of L. M. Lambe, "Palæoniscid fishes from the Albert shales of New Brunswick,"[90] published in 1910.

The following specimens are in the Buffalo museum. They are from the type locality, the Albert Mine (Lower Carbonic), Albert County, New Brunswick. Carll collection.

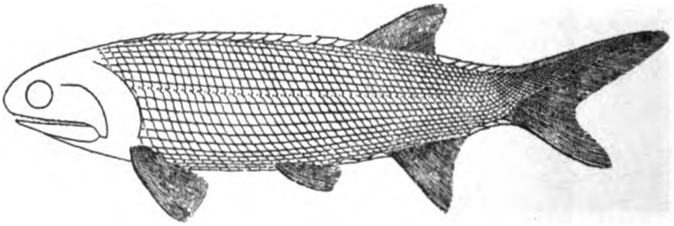

FIG. 63. RESTORATION OF *Rhadinichthys alberti* (Jackson). AFTER LAMBE

E 2112 Imperfect fish on a piece of shale.

E 2113 Imperfect fish.

E 2114 Imperfect fish.

E 2115 Imperfect fish.

E 2116 Imperfect fish.

E 2117 Imperfect fish, showing caudal fulcra; also detached flank and ridge scales.

E 2120 Detached flank and ridge scales.

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[90] *Contributions to Canadian Pal.*, vol. iii, Mem. 3, pp. 1–68, pls. i–xi.

Rhadinichthys elegantulus (Eastman)

(Pl. 66; text-fig. 64)

Elonichthys elegantulus EASTMAN, Rept. Geol. Surv. Iowa, xviii, 274. 1908.
Elonichthys elegantulus L. M. LAMBE, Contrib. to Canadian Pal., iii, Mem. 3, p. 30. 1910.

In 1908 Eastman gave the name *Elonichthys elegantulus* to a small palæoniscid found associated with *Rhadinichthys alberti* in the Lower Carboniferous of Albert County, New Brunswick. In 1910, Lambe discussed some of the characters of the species and expressed doubt as to its validity. He writes:

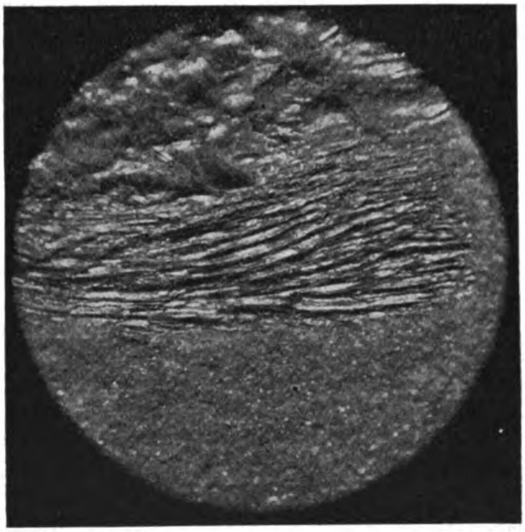

FIG. 64. *Rhadinichthys elegantulus* (Eastman). PECTORAL FIN, ENLARGED. E 2094

"Its small size, in conjunction with its generally imperfect state of preservation, leads one to suspect that it may be the young of one of the species already known from this locality, possibly of *R. alberti.* Of the many scores of specimens in our collections, nearly all lack proper definition of outline, and the head is, as a rule, very imperfectly preserved."[91]

In the Buffalo museum there are a number of specimens of this

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[91] Loc. cit., p. 30.

species which were collected by the late John F. Carll. They have enabled us to draw up the following diagnosis.

Revised description.—A species of small size, about 45 mm. in length. Greatest depth of body just behind the pectoral arch, the trunk tapering rapidly backward from this point.

Dorsal and anal fins almost opposite, large, triangular, longer than high, with rays which branch distally. Caudal strongly heterocercal, the upper lobe being nearly twice the lower, the fin-rays slender, and distally branching; pectoral fins moderately large, their principal rays unarticulated; provided with minute, slender fulcra; ventral fins short-based and about equidistant from pectoral and anal. Lateral line present.

From the above emended description it appears that this species belongs to the genus *Rhadinichthys* rather than to *Elonichthys*, to which we accordingly assign it.

E 2092 Complete fish, 45 mm. in length, showing head and all fins. (Pl. 66, figs. 1, 2.)

E 2093 Imperfect fish, showing well the anal and dorsal fins. (Pl. 66, fig. 3.)

E 2094 Complete fish, showing head in ventro-lateral aspect; pectoral, pelvic and anal fins. (Fig. 64.)

E 2095 Small slab with the remains of several fishes. One specimen in lateral aspect shows detail of all fins.

E 2096 Slab with several fragmentary fishes showing cranial bones and pectoral fins. On same slab is a scale of *Rhadinichthys alberti* (Jackson).

E 2097 Imperfect fishes on small slab.

E 2098 Imperfect fishes on small slab.

E 2099 Cranium, shown in inner view.

E 2100 Imperfect fish.

E 2101 Imperfect fish.

E 2102 Imperfect fish.

E 2103 Imperfect fish.

E 2104 Imperfect fishes on small slab. They show position of dorsal and anal fins.

E 2105 Imperfect fish.

E 2106 Imperfect fish; shows mandible and maxilla in position.

E 2107 Imperfect fish; shows the cranial bones

E 2108 Imperfect fish.

E 2109 Imperfect fish.

E 2110 Imperfect fish.

E 2121 Fish showing head and all fins.

Elonichthys browni (Jackson)

This species was recently restudied by Lambe,[92] who published an extended account of it together with splendid figures of complete fishes and of details of the scales. It is the largest of the palæoniscids found in the Albert Mine, New Brunswick, the fishes ranging in size, according to Lambe, from 18.5 to 35.5 cm.

E 2111 Detached scales from posterior portion of trunk.
Lower Carboniferous; Albert County, New Brunswick. Carll collection.

Haplolepis [Eurylepis] tuberculata (Newberry)

E 2088 Small complete fish on coal.
Coal Measures; Linton (now Yellow Creek), Jefferson County, Ohio. Presented by J. S. Newberry.

Haplolepis [Eurylepis] granulata (Newberry)

E 2089 Small complete fish on coal. There is some doubt whether this species is distinct from the preceding; in fact, all the species of *Haplolepis* are in need of revision. Other data same as preceding.

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[92] Lambe, L. M.: Palæoniscid fishes from the Albert shales of New Brunswick. *Contrib. Canadian Palæont.*, iii, 22, pls. iv–ix, 1910.

Family CATOPTERIDÆ

Catopterus gracilis J. H. Redfield

E 2125 Fish with all fins.

Newark series (Triassic); Boonton, N. J. Presented by J. S. Newberry.

Catopterus redfieldi Egerton

E 2124 Nearly complete fish. On the same slab is a nearly complete fish of *Semionotus fultus*.

Other data same as preceding.

Genus **Dictyopyge** Egerton

This genus is closely related to *Catopterus*, differing chiefly in the more forward position of the dorsal fin, which begins a little in front of the anal. The genus is widely distributed, being known by eight or nine species, occuring in North America, Europe, Australia, and probably also in South Africa.

Dictyopyge macrura (W. C. Redfield)

(Pl. 24, fig. 3; Pl. 67)

This is one of the rarest of North American fossil ganoids, known by only one or two complete specimens and a number of fragments. Until recently the type specimen had been lost, but it was lately found by Dr. A. S. Woodward; it had been in use as a paper weight in one of the offices in the British Museum.

Dictyopyge macrura is known from only one locality—the Upper Triassic shales, near Richmond, Va. Eastman[93] has referred to a specimen in the Museum of Comparative Zoology at Cambridge, Mass., (No. 2531), which is labelled "probably from Middletown, Connecticut," and has accepted it as evidence of the occurrence of the species in the Triassic of the Connecticut Valley. But to us this specimen does not seem to afford conclusive evidence of the occurrence of the species in Connecticut. The fact that the label reads "probably," indicates that it was not written by the hand that collected the specimens; or if so, only after so long an interval since it was collected,

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[93] Eastman, C. R.: Triassic fishes of Connecticut. *Bull. No.* 18, *State Geol. and Nat. Hist. Survey*, Connecticut, p. 56, 1911.

that the circumstances were hazy in the writer's mind; and in fact he may have confused his specimen with some other. Obviously the label cannot carry conviction. Furthermore, among the various collections of fishes from the Connecticut Valley Trias there is not a single specimen of *Dictyopyge,* notwithstanding that hundreds of specimens have been collected. Although this fact, being mere negative evidence would not in itself be conclusive, still it lends force to the argument that the label on the specimen is probably incorrect. In any event, there is no positive proof at present that *Dictyopyge* occurs anywhere else but in the Richmond, Va. locality.

We may note that at the time Newberry[94] studied this species, specimens were abundant at the type locality, and numbers were frequently found on one slab, as in the case of specimens of *Semionotus* from the Karoo formation of South Africa. Newberry mentions a slab which "though scarcely more than a foot square, carried impressions of over forty individuals."[95]

The Buffalo Museum is fortunate in possessing a slab of shale containing remains of ten fishes, two or three of them almost complete (Pl. 67). From a study of this specimen we are able to give a revised description of the species.

Revised description.—Fish gracefully fusiform, attaining a length of 15 cm. Head contained five times, and greatest depth six times in the total length. Dorsal originating in advance of anal; triangular, about ½ the size of anal. Anal the largest of all the fins, arising opposite middle of dorsal and extending beyond beginning of caudal; with about 25 broad, robust articulated rays; its posterior margin rounded, not straight. Caudal heterocercal, with about 35 rays; its upper lobe fringed with about 50 small fulcra giving the margin a braided appearance. Pectoral relatively small. Ventral with 10 to 12 robust rays anteriorly margined with minute fulcra. Cranial bones ornamented with scale-like confluent tubercles and irregular intersecting ridges (Pl. 24, fig. 3). Scales smooth and highly polished. Lateral line prominent.

The single specimen in the collection may be described as follows:

E 2126 A slab of shale 25 by 17 cm., containing the remains of 10 fishes, two of them more or less complete, (Pl. 67).

Triassic coal beds; Richmond, Va. The specimen was

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[94] Newberry, J. S.: Fossil fishes and fossil plants of the Triassic rocks of New Jersey and the Connecticut Valley. *Monograph U. S. Geol. Surv.*, xiv, 64, 1888.

[95] Loc. cit. p. 65.

collected many years ago by Mr. David F. Day, who presented it to the Museum.

Family LEPIDOTIDÆ

Lepidotus maximus Wagner

E 2154 Cast of a portion of the trunk of a large fish, showing scales.
Lithographic slate (Upper Jurassic); Solnhofen, Bavaria.

E 2156 Cast of a large fish, showing dentition and fins. Lithographic slate (Upper Jurassic); Solnhofen, Bavaria.

Lepidotus minor Agassiz

E 2160 Cast of a large fish, shown in side view; all the fins are present, and the head is fairly well shown.
Upper Oolite; Isle of Portland, England.

Family SEMIONOTIDÆ

Semionotus fultus (Agassiz)

E 2122 Fish with all the fins.
Newark series (Triassic); Boonton, N. J. Presented by J. S. Newberry.

Semionotus tenuiceps (Agassiz)

E 2123 Nearly complete fish.
Other data same as preceding.

Family PYCNODONTIDÆ

Gyrodus circularis Agassiz

E 2155 Cast of a fish, showing the cranium, facial bones, dental apparatus and all the fins.
Lithographic slate (Upper Jurassic); Solnhofen, Bavaria.

Microdon elegans Agassiz

E 2159 Cast of a fish, showing all the fins.
Upper Jurassic; Kelheim, Bavaria.

Family ASPIDORHYNCHIDÆ

Aspidorhynchus acutirostris (Blainville)

E 2567 Fish lacking head and caudal extremity. Length as far as preserved, 40 cm.; greatest depth of body, 6.5.
Lithographic slate (Upper Jurassic); Solnhofen, Bavaria.

E 2158 Cast of a fish, shown in side view.
Lithographic slate (Upper Jurassic); Eichstädt, Bavaria.

Family LEPISOSTEIDÆ

Lepisosteus simplex Leidy

(Pl. 68)

Although a dozen species of fossil gar pikes have been named from various localities in North America,[96] only three are known by complete fishes; the others are represented by vertebræ, scales or head plates, and are not satisfactorily defined. The species represented by whole fishes are:

1. *Lepisosteus atrox* Leidy—Green River shales (Eocene), Wyo.
2. *Lepisosteus simplex* Leidy—Green River shales (Eocene), Wyo.
3. *Lepisosteus* (Clastes) *cuneatus* (Cope)—Miocene, Utah.

Of these, the best represented species is *L. simplex*, known by at least three splendid specimens—one in the United States National Museum,[97] a second from the Eocene of Utah,[98] and a third, undescribed, in the American Museum. To these three we may now add a fourth specimen—a splendid fish which even surpasses the preceding ones in size, preserved in the Buffalo Museum. It is from the type locality, the Green River shales of Wyoming. We base the identification of the species chiefly on the character of the fins, which

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[96] Hay, *Bibliography and catalog fos. Vert. N. Amer.*, p. 377.

[97] Eastman, C. R.: Fossil Lepidosteids from the Green River Shales of Wyoming. *Bull. Comp. Zool.* xxxvi, 74, pl. i, fig. i, 1900.

[98] Briefly described by Prof. T. D. A. Cockerell in *Science*, n. s., xxix, 796, 1909.

are rather weaker than in *L. atrox*, and upon the ornamentation of the scales. These appear perfectly smooth to the naked eye, except for one, or sometimes two, large punctæ near their centres, while under a lens the entire surface is seen to be covered with minute pittings.

The fossil was obtained some years ago from a track hand, in Wyoming, by the late Dr. Ernest Wende, formerly a director of the Buffalo Society of Natural Sciences; it later became the property of the Society through the kindness of Mrs. Wende.

E 2150 A gar pike 88 cm. in length, on a slab of shale (Pl. 68). The fish is shown in lateral view, except the head, which rests on its dorsal surface, displaying the inside of the cranium. All the fins are shown—more beautifully, in fact, than in any other specimen hitherto known. The left pectoral is shown above the right, and the same is also the disposition of the ventrals.

In the head, the left maxilla is detached and lies above its mate, with its large laniary teeth overlapping the mandible—as seen near the bottom of the figure. The vomer, palatines, and parasphenoid are very little disturbed. The facial bones are badly crushed, but both cleithra are preserved. Little can be said as to the external ornamentation of the head plates, except that the outer surface of the left cleithrum seems to be covered with fine, oblique striations. The mandibles and maxillæ each bear a double series of teeth, and the vomer and palatines are covered with short conical teeth.

The longest vertebral centrum exposed (above base of ventral fin), measures 1.2 cm. in length.

The pectoral fin has 9 rays, and shows a series of slender fulcra. The ventrals are nearer the anal than the pectoral, have 5 rays, and are armed with biserial fulcra. The anal has 8 or 9 rays, the dorsal 7. The latter begins about opposite the origin of the anal. The caudal, which is completely preserved, is rounded posteriorly, and has 15 rays. The fulcra of its upper margin are slender, and apparently in a single series; those of the lower margin are robust and biserial.

The ornamentation of the scales has already been referred to above. The squamation is much disturbed in the front half of the fish, exposing to view the vertebral centra and ribs; while in the posterior part of the fish the scales are hardly disarranged. There are at least 50 transverse rows of scales in the length of the fish.

Measurements	*cm.*
Total length (including caudal)	88
Depth, behind pectoral arch	15
Length of head	26
Length of pectoral	8
Length of ventral	10
Length of anal	10
Length of dorsal	10
Length of caudal	12
Length of mandible	16

Family AMIIDÆ

Megalurus elegantissimus Wagner

E 2157 Cast of a fish 11 cm. in length, showing all the fins.
Lithographic slate (Upper Jurassic); Solnhofen, Bavaria.

Family PHOLIDOPHORIDÆ

Pholidophorus sp.

E 2599 Head and anterior portion of trunk.
Lithographic stone; Solnhofen, Bavaria.

Family CLUPEIDÆ

Diplomystus brevissimus (Blainville)

This species is represented by three specimens, collected by Mrs. C. B. Hoyt. They are from the type locality and formation—Upper Cretaceous; Mt. Lebanon, Syria.

E 2128 Slab of limestone with four finely-preserved fishes.

E 2129 Slab with four fishes.

E 2130 Complete fish on limestone, showing all fins.

Knightia [Diplomystus] humilus (Leidy)[33]

E 2149 Small fish on a piece of shale.
Green River shales (Eocene); Wyoming.

Family OSTEOGLOSSIDÆ

Phareodus testis (Cope)

E 2147 Complete fish with well-preserved head, showing teeth and with all fins. Total length, 33 cm.
Green River shales, (Eocene); Twin Creek, Wyoming.

E 2148 Head of a large fish with finely preserved teeth.
Formation and locality same as preceding. Collected by Dr. Ernest Wende.

Family BERYCIDÆ

Hoplopteryx superbus (Dixon)

E 2163 Cast showing five fishes on a slab.
Cretaceous; Lewes, England.

Coprolites

E 2118 and **E 2119** Two Coprolites.
Lower Carboniferous; Albert County, New Brunswick. Carll collection.

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[33] We follow D. S. Jordan, who proposed *Knightia* as a generic name for a section of *Diplomystus*, with *Diplomystus humilus* Leidy, as the type species. *Univ. California Publ. Bull. Dept. Geol.* No 5 p. 136, 1907.

PLATES

PLATE 1

Restoration of the head and dorsal armor of *Dinichthys magnificus*, n. sp., viewed from in front. × ⅛. Type specimen. See p. 36. (Mounted for exhibition by W. L. Bryant.)

PLATE 1

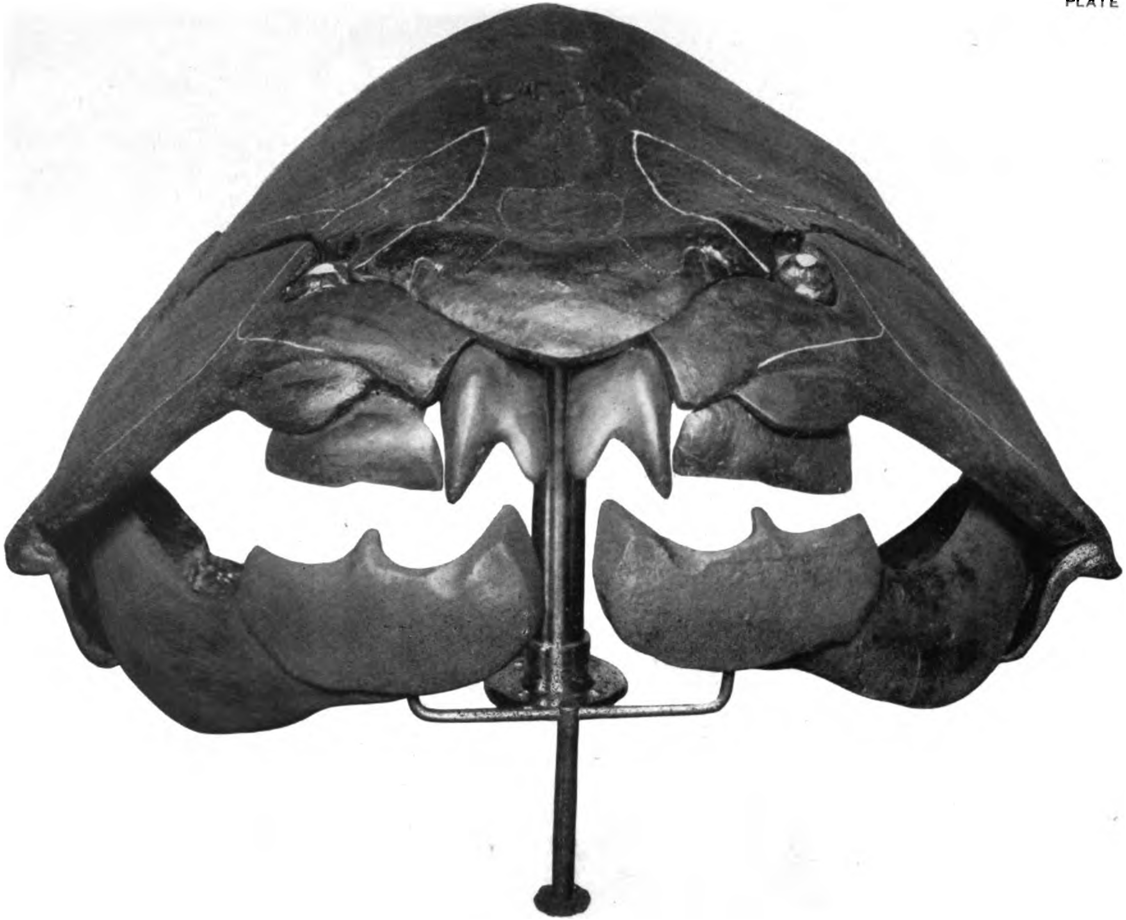


PLATE 2

Section on Eighteen Mile Creek, showing exposure of the Genesee and lower portion of the Portage. The Conodont bed is absent in this section.

A,	Cashaqua shale	Portage
B,	Middlesex shale	
C,	West River shale	Genesee
D,	Genundewa limestone	
E,	Genesee shale	

(See text-fig. 2)


A
B
C
D
E

PLATE 3

Upper: Lower part of a section on Eighteen Mile Creek where the Conodont bed is best developed.

A, West River shale
B, Genundewa limestone
C, Conodont bed
D, Genesee shale
(See text-fig. 2)

Lower: Section at same level as the above but a few hundred feet away, showing absence of the Conodont bed. (This is an enlarged view of the lower part of section shown in Plate 2, immediately to the left of the camera box seen in that picture.)

A, West River shale
B, Genundewa limestone
D, Genesee shale


A
B
C
D


A
B
D

PLATE 4

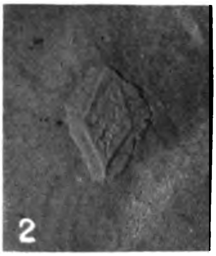
Figs. 1, 2, 3. *Coccostus parvulus*, n. sp. Cotypes, about natural size. The specimens are impressions in shale, and the figures are from squeezes made from them. Originals of 1 and 3 are on one slab. Page 29.

1. Two cranial plates, showing the tuberculated ornamentation. E 2371.
2. Postero-medianventral, showing outer, ornamented face. E 2372.
3. Median occipital, in inner, or visceral view. E 2371.

Fig. 4. *Coccosteus* sp. Postero-ventromedian, in inner view; about natural size. E 2377, p. 31.

Fig. 5. *Coccosteus* sp. Postero-ventromedian, in outer view. × $\frac{3}{4}$. E 2376, p 31.


1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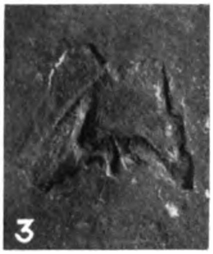
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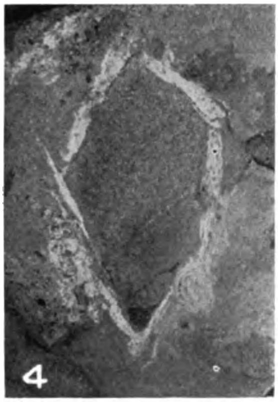
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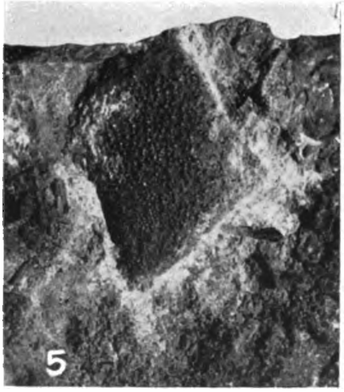
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PLATE 5

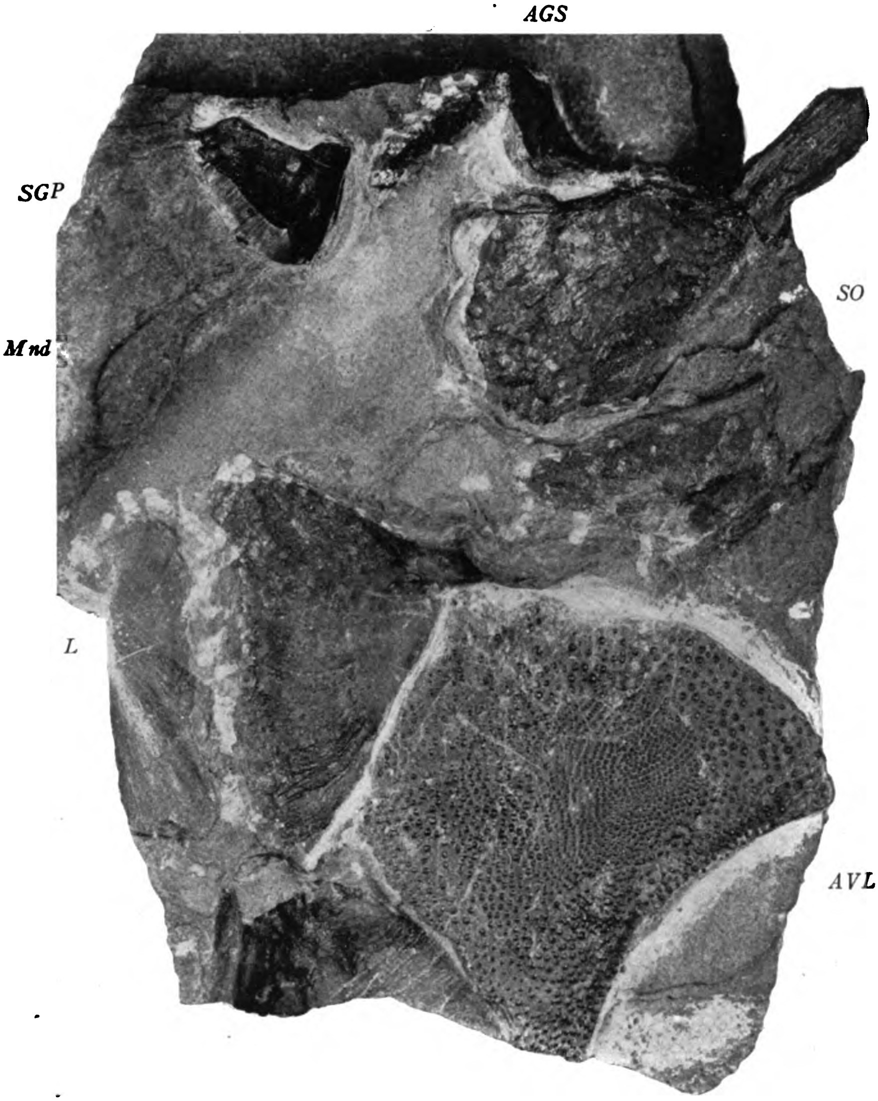
Coccosteus canadensis Woodward

Upper Devonic; Scaumenac Bay, Quebec, Canada

Fig. 1. Plates in matrix, × $\frac{2}{3}$, p. 27. *ASG*, left antero-superognathal, in inner view; *AVL*, left antero-ventrolateral, outer view. (Posterior half is lacking.) *L*, lower arm of lateral, inner view; *Mnd*, impression of mandible, lacking anterior extremity; *PSG*, left postero-superognathal, inner view; *SO*, left suborbital, inner view. E 2374.

Fig. 2. Postero-superognathal, shown in figure 1, natural size.

Fig. 3. Antero-superognathal, shown in figure 1, natural size. It shows the functional region well and the articulating process.


AGS
SGP
SO
Mnd
L
AVL


2


3

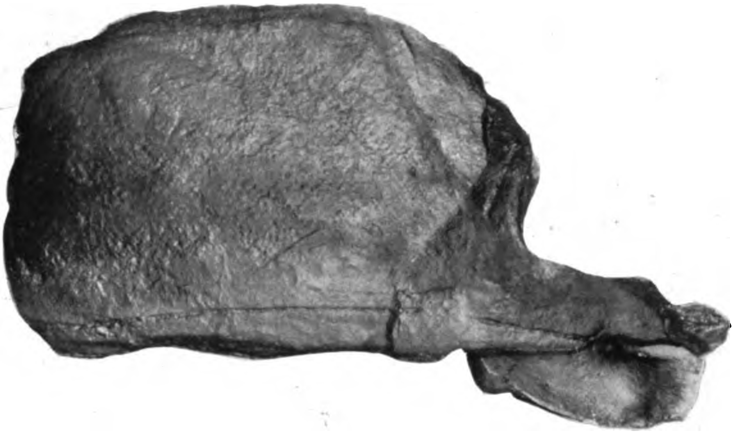
PLATE 6

Dinichthys terrelli Newberry

Cleveland shale (Upper Devonic); Linndale, near Cleveland, Ohio

Fig. 1. Right suborbital, outer view, × ⅓. The specimen is an impression in shale and the figure is of a cast made from it. E 2380, p. 32.

Figs. 2, 3. Left mandible, in outer (2), and inner (3), views. × ⅓. E 2379, p. 32.



1

2

3

PLATE 7

Dinichthys magnificus, n. sp.

Plates belonging to type specimen, E 2381. Near base of Rhinestreet shale (Portage); Eighteen Mile Creek, near Hamburg, N. Y.

Fig 1. Left mandible, lacking blade, or inserted portion, in outer view. Somewhat less than × ½, p. 41.

Fig. 2. Right lateral, or "clavicular," in outer view, × ⅓. Figure is of a *cast*, of the specimen, which is an impression, p. 42.

Fig. 3. Right postero-ventrolateral, in outer view. × ¼. Figure is of a *cast* of the specimen, which is an impression, p. 43.

PLATE 8

Figs. 1, 1a. *Dinichthys magnificus*, n. sp. Anterior extremity of a left mandible, × ¾. 1, outer view; 1a, inner view. E 1936, p. 43.

Fig. 2. *Dinichthys magnificus*, n. sp. Posterior, or inserted portion of a right mandible, × ½. The black portion of the figure is represented by the impression, the rest by actual bone. E 1960, p. 44.

1

1a

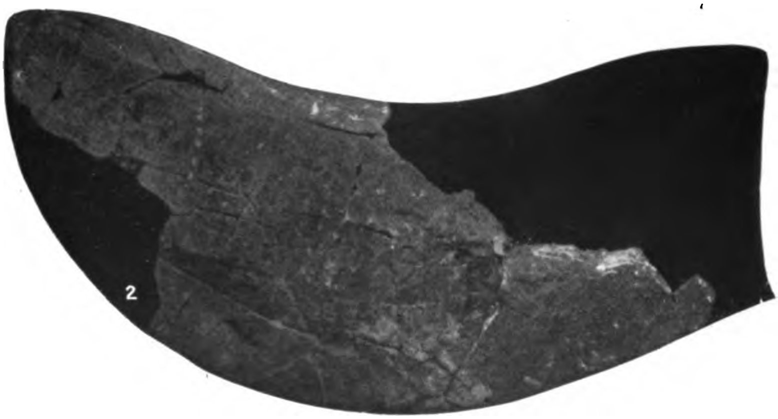


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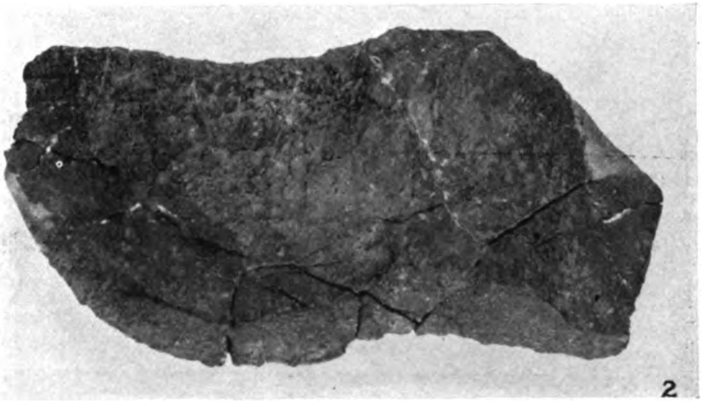
PLATE 9

Dinichthys magnificus, n. sp.

Figs. 1, 2. Small left postero-superognathal; natural size. 1, outer view; 2, inner view. E 1942, p. 45.

Fig. 3. Imperfect large left postero-superognathal, outer view. Natural size E 1937, p. 44.

1



2

3

PLATE 10

Dinichthys newberryi Clarke

Figs. 1, 1a. Left antero-superognathal of a young individual, in inner (1), and outer (1a), views; natural size. E 1940, p. 49.

Fig. 2. Functional half of a left mandible, in matrix; outer view. × $\frac{5}{6}$. E 2382, p. 48.

PLATE 10

1

1a

2

PLATE 11

Dinichthys newberryi Clarke

Figs. 1, 1a. Left antero-superognathal, in outer (1), and inner (1a), views; natural size. E 1939, p. 48.

Figs. 2, 2a. Juvenile left antero-superognathal, in outer (2), and inner (2a), views; slightly larger than natural size. E 1955, p. 49.

1

2

1a

2a

PLATE 12

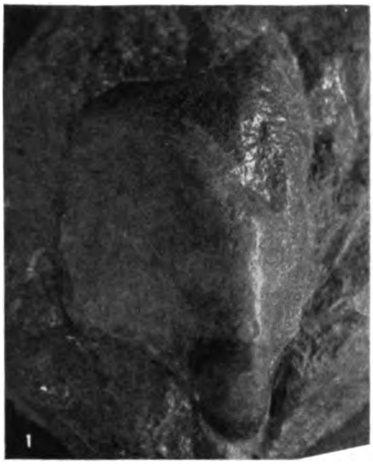
Dinichthys pustulosus Eastman

Hamilton limestone (Mid Devonic); Milwaukee, Wis. Originals in private collection of Mr. E. E. Teller, Buffalo, N. Y.

Fig. 1. Left antero-superognathal, in outer view. × ⅔. Cast of specimen E 2384, p. 51.

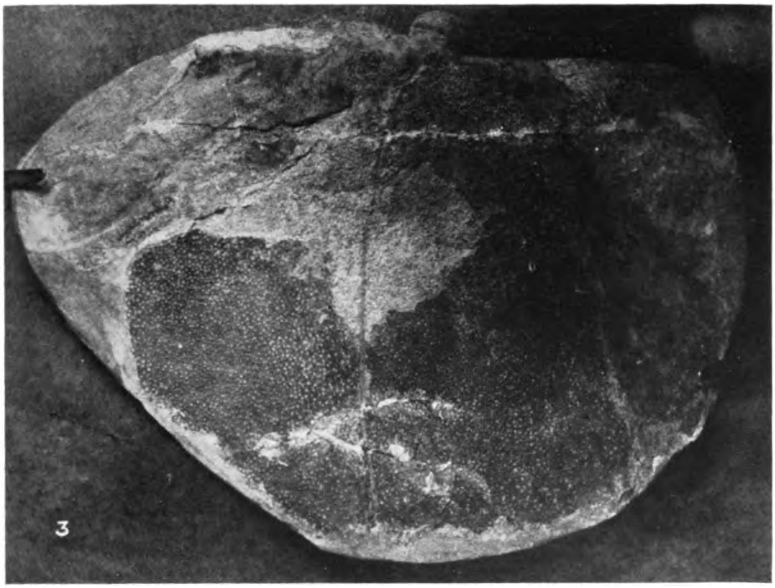
Fig. 2. Cast of antero-ventromedian, in outer view, showing ornamentation of fine tubercles, and extent of ornamented area. × ¾. E 2385, p. 51.

Fig. 3. Right antero-dorsolateral, in outer view; margins restored. P. 51.



1

2



3

PLATE 13

Fig. 1. *Dinichthys pustulosus* Eastman. Rostral element in matrix; outer view. It shows the ornamentation well. Original in private collection of E. E. Teller, Buffalo, N. Y.

Fig. 2. Ditto. Beak of a right mandible, in inner view, showing row of symphyseal denticles (*s*). Natural size. E 1896. p. 51.

Fig. 3. *Dinichthys* sp. "Tooth" of a left antero-superognathal. × ¾. (By inadvertance printed upside down.) E 1958, p. 62.

Fig. 4. *Dinichthys pustulosus* Eastman. Left marginal of a small cranium, showing sensory canal. × ⅔. E 1973, p. 52.

Fig. 5. *Dinichthys* sp. Half of a postero-dorsolateral, in outer view. × ½. E 1998, p. 63.


1

2


3

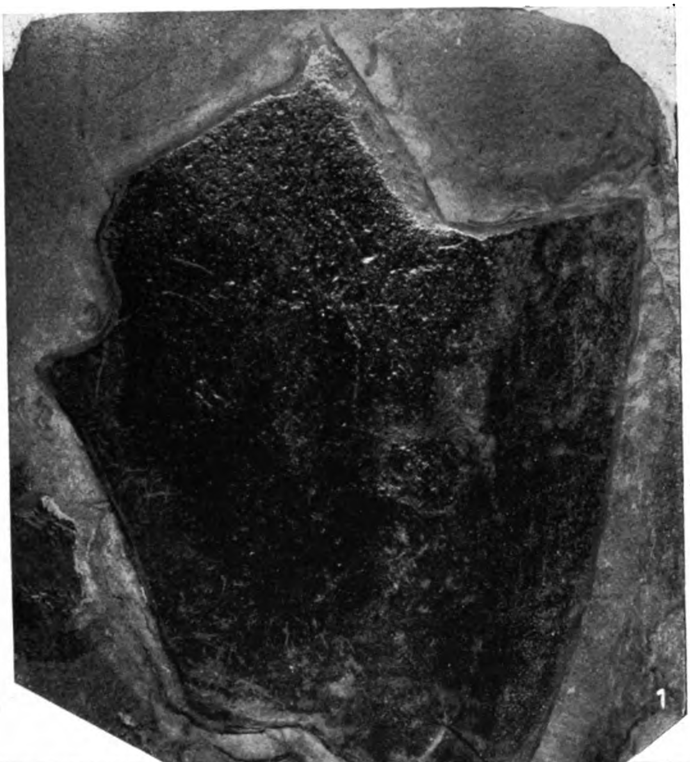

4


5

PLATE 14

Fig. 1. ***Dinichthys*** sp. Incomplete postero-ventrolateral, in matrix. Natural size. E 2511, p. 65.

Fig. 2. ***Dinichthys*** sp. Functional half of a right mandible, in outer view; much worn by use. Natural size. E 2510, p. 61.



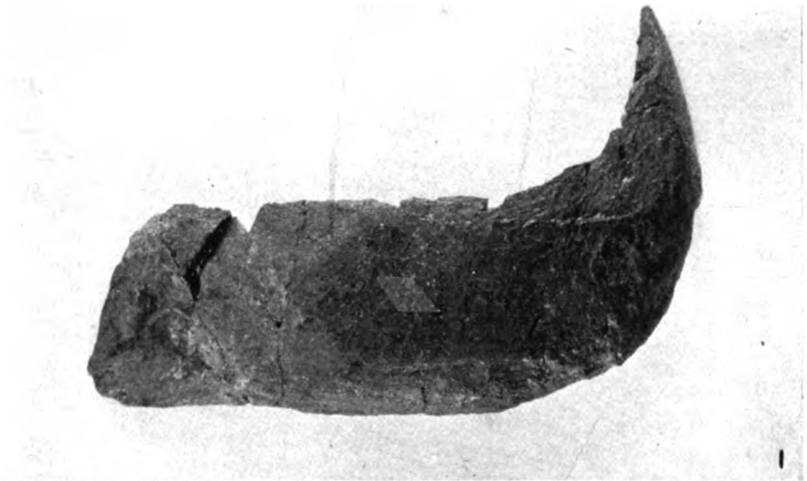
1

2

PLATE 15

Fig. 1. *Stenognathus gouldi?* (Newberry). Anterior half of right mandible; outer view. Natural size, E 2392, p. 71.

Fig. 2. *Stenognathus ringuebergi* Newberry. Type. Dorsomedian. × $\frac{3}{4}$. P. 69. Original in private collection of Mr. E. N. S. Ringueberg, Lockport, N. Y.



1

2

PLATE 16

Figs. 1, 1a. ***Dinichthys*** sp. Right postero-superognathal, in outer (1), and inner (1a), views. Natural size. E 1943, p. 62.

Fig. 2. ***Dinichthys*** sp. Right postero-superognathal, in matrix; inner view; natural size. E 2388, p. 62.

1

1a

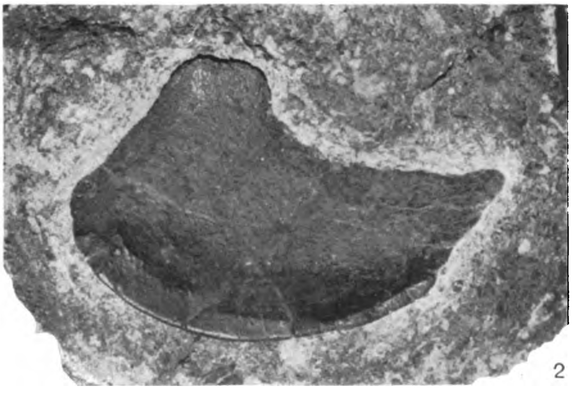


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PLATE 17

Fig. 1. *Dinichthys magnificus?* Rostral element in matrix; outer view. × ½. E 1981, p. 60.

Fig. 2. *Dinichthys* sp. Fragmentary plate ornamented with tubercles. × ¾. E 1996, p. 63.

Fig. 3. *Dinichthys* sp. Fragmentary plate ornamented with small tubercles; natural size. E 1997, p. 64.


1


2


3

PLATE 18

Fig. 1. *Dinichthys* sp. A very small left antero-superognathal, × 5. This is the smallest antero-superognathal of *Dinichthys* ever found. E 1951, p. 61.

Fig. 2. *Dinichthys* sp. A juvenile right antero-ventrolateral; natural size. E 2389, p. 63.

Fig. 3. *Dinichthys* sp. Spiniferous plate, imperfect at one extremity, in matrix. $\times \frac{2}{3}$. E 2011, p. 64.

1

2

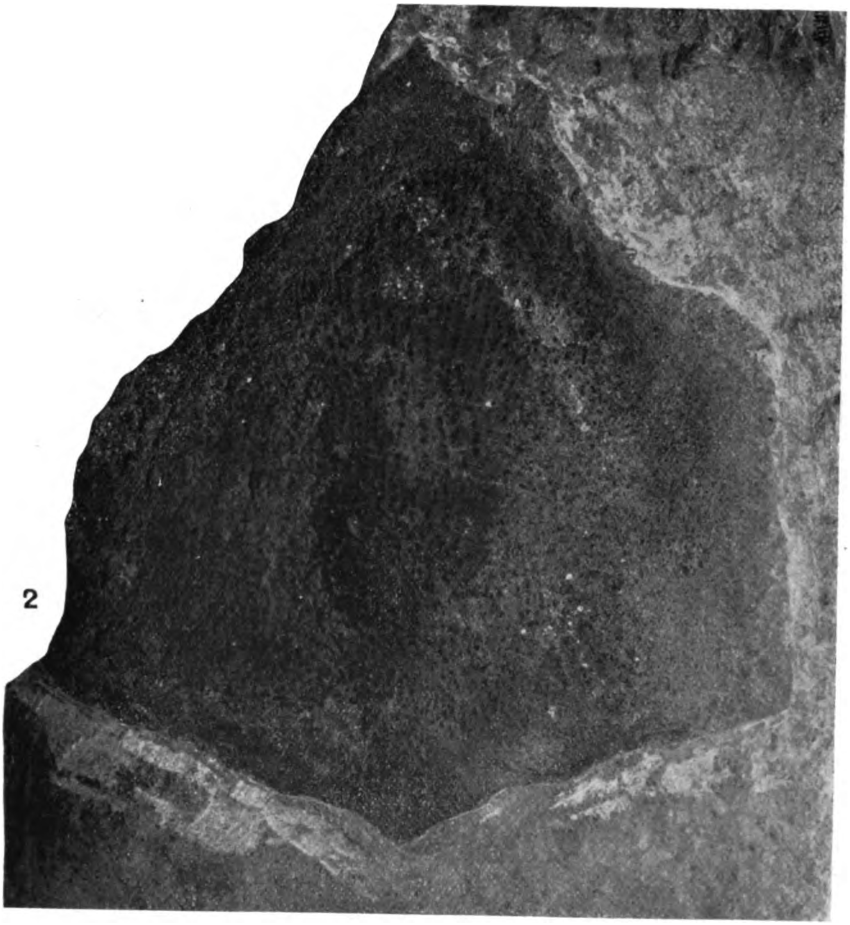
3

PLATE 19

Fig. 1. *Titanichthys* sp. Anterior third of a small right mandible, in inner, or oral, view. The anterior extremity is restored, and posteriorly the outer face is embedded in matrix. × ½. E 2391, p. 65.

Fig. 2. *Dinichthys* sp. Median occipital, ornamented with small tubercles arranged in linear series radiating from a center; in matrix. Natural size. E 2008, p. 60

1



2

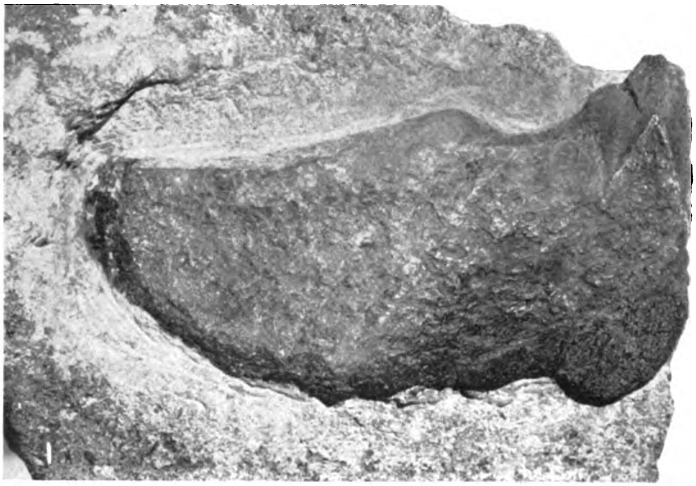
PLATE 20

Figs. 1, 1a, 1b. *Perissognathus aduncus*, n. g., n. sp. Type. Right mandible in matrix; outer view. Natural size. E 2397, p. 81.

1a. Symphyseal region of type, showing the row of upturned symphyseal denticles. Natural size.

1b. Another view of same.

Fig. 2. Small element, probably a lateral of an indeterminate Arthrodire. Natural size. E 1988, p. 97.


1


1a


1b


2

PLATE 21

Figs. 1, 1a, 1b. *Machærognathus woodwardi*, n. g., n. sp. Type. Right mandible, lacking posterior extremity, × ⅔. E 1935, p. 83.

1, outer view; 1a, inner view; 1b, as it appears resting on the outer face, to show sigmoidal curvature, antero-posteriorly.

Fig. 2. *Stenognathus insignis*, n. sp. Type. Right mandible, in outer view. × ⅘ E 1932, p. 73.

1

1a

1 b

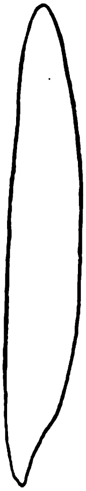
2

PLATE 22

Fig. 1. *Dinichthys magnificus*, n. sp. Cast of postero-ventrolateral belonging to type specimen; inner view. × $\frac{1}{4}$. E 2381, p. 42.

Fig. 2. *Copanognathus crassus*, n. g., n. sp. Microsection of type mandible, p. 84.

Fig. 3, 4. *Copanognathus crassus*, n. g., n. sp. Sections of type mandible; natural size. 3, section near posterior extremity; 4, section at about first third, p. 84



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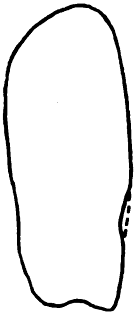

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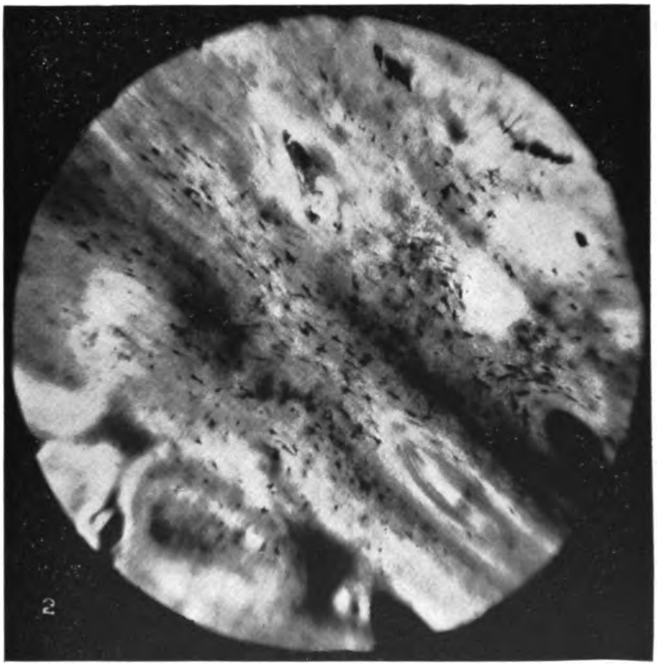

PLATE 23

Fig. 1. *Dinomylostoma buffaloensis*, n. sp. Right mandible, in matrix; outer view. × ¾. E 1964, p. 88.

Fig. 2. *Dinomylostoma* sp. Left mandible of a juvenile individual. × 1⅓. E 2042. p. 90.


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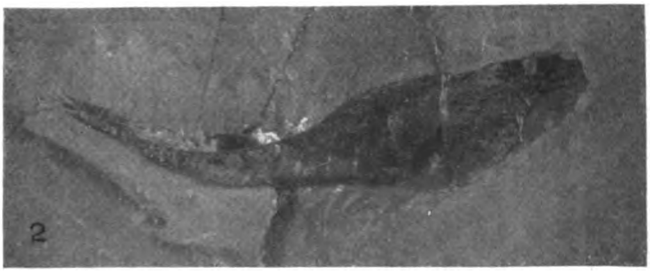
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PLATE 24

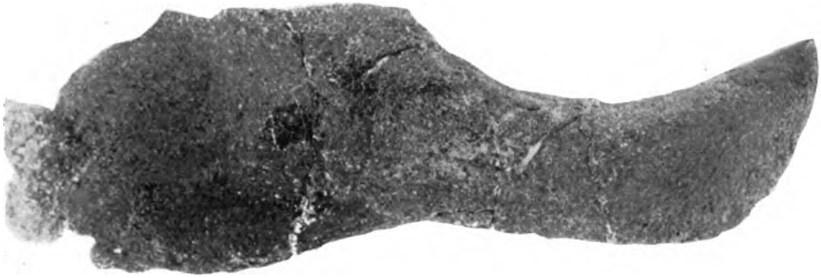
Fig. 1. *Dinomylostoma buffaloensis*, n. sp. Cotype. Right mandible, lacking posterior half of inserted portion, in outer view. Natural size. E 1961, p. 86.

Fig. 2. *Dinomylostoma buffaloensis*, n. sp. Cotype. Left mandible, lacking only a very little of the posterior extremity; in inner view. A part of outer face is embedded in matrix. × about ⅔. E 1965, p. 86.

Fig. 3. *Dictyopyge macrura* (W. C. Redfield). Fragment of head plate enlarged 10 times, to show style of ornamentation. E 2126, p. 193.

Fig. 4. *Dinomylostoma buffaloensis*, n. sp. Functional half of a left mandible; inner view. × ⅔. E 1966, p. 88.

Fig. 5. *Dinomylostoma buffaloensis?* Functional half of a left mandible; outer view. × ⅔. E 1968, p. 89.



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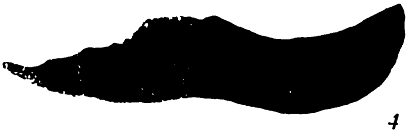

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PLATE 25

Aspidichthys notabilis Whiteaves

Right antero-ventrolateral, incomplete anteriorly; outer view. The posterior extremity is restored from a squeeze of impression in the matrix. × ¾. E 1970, p. 93.

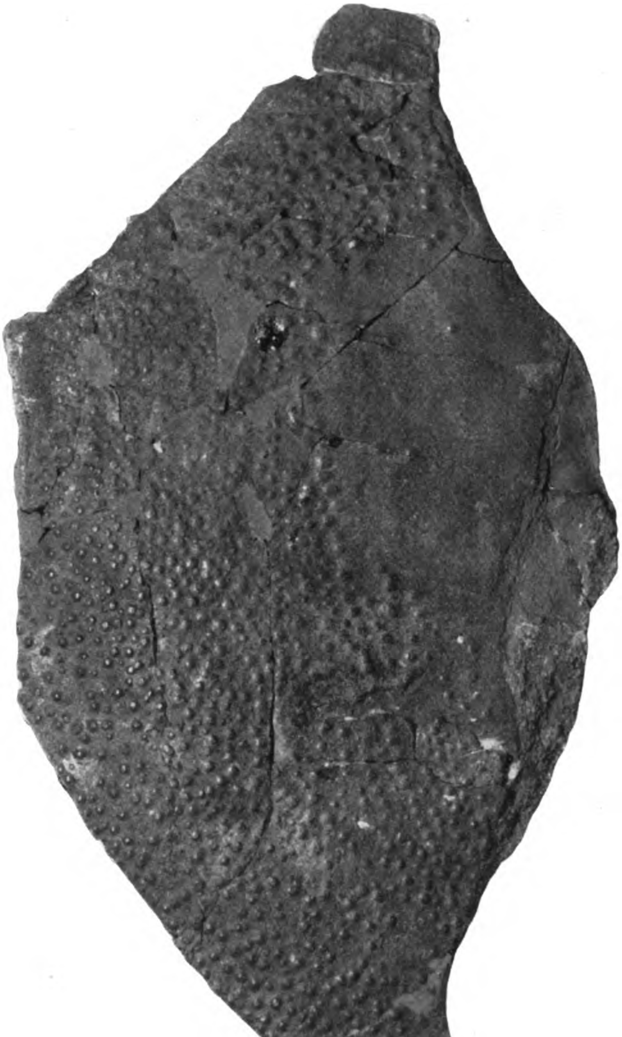

PLATE 26

Aspidichthys notabilis Whiteaves

Fig. 1. Front half of antero-ventromedian. Photographed from a cast, original being an impression. Natural size. E 2399, p. 93.

Fig. 2. Fragmentary plate, perhaps part of a ventral. × ⅔. E 1971, p. 93.

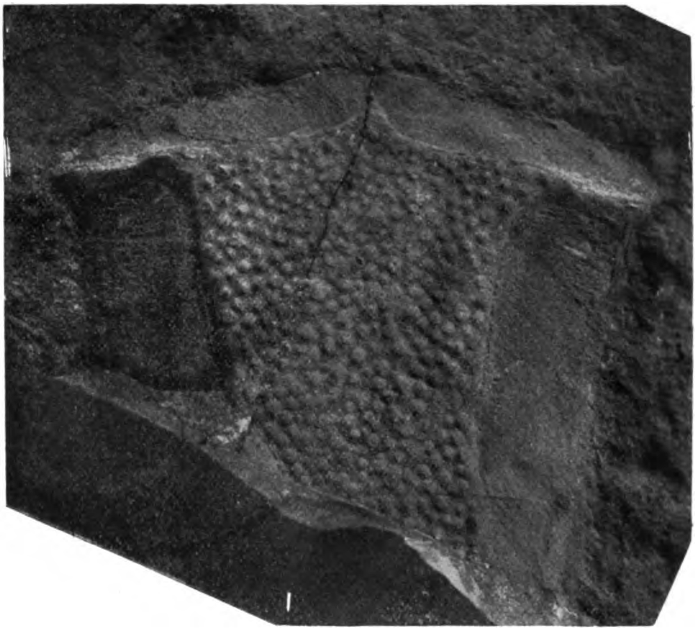

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PLATE 27

Fig. 1. *Dinichthys* sp. Juvenile right antero-superognathal, in outer view; natural size. E 1954, p. 62.

Fig. 2. *Dinichthys newberryi?* juvenile. Left antero-superognathal, in outer view; natural size. E 1956, p. 49.

Fig. 3. *Dinichthys insolitus*, n. sp. Type. Right antero-superognathal. Natural size. E 2387, p. 53.

Figs. 4, 4a. *Perissognathus aduncus*, n. g., n. sp. Beak of a left mandible of about same size as the type (see Pl. 20), showing the symphyseal denticles well. Natural size. 4, outer view; 4a, inner view. E 2165, p. 83.

Figs. 5, 6. *Dinomylostoma?* Two upper dental elements, in oral view. Natural size. E 1859 and E 2398, p. 90.

Fig. 7. Small left antero-superognathal of an undetermined Arthrodire. × $\frac{3}{4}$ E 1946, p. 96.

1

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4a

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PLATE 28

Fig. 1. *Dinichthys?* Plate in matrix, outer view; natural size. E 2035, p. 65.

Fig. 2. Dinichthyid, sp. indet. Very small juvenile lateral, or "clavicular," in matrix; outer view. × 2. E 2043, p. 97.

Fig. 3. *Dinichthys newberryi?* Postero-ventromedian. × $\frac{3}{5}$, E 1986, p. 50.

Fig. 4. *Acanthaspis* sp. Detached lateral spine. × 2. E 2013, p. 100.


1


2

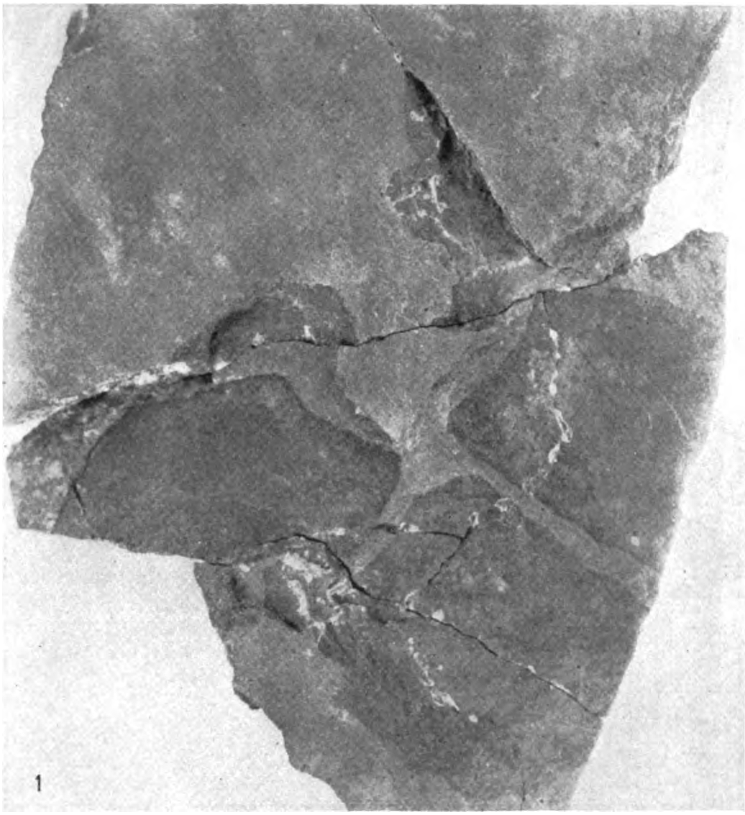

3


4

PLATE 29

Fig. 1. *Selenosteus?* sp. Ventral plates, natural size. E 2022, p 81.

Fig. 2. *Eczematolepis fragilis* (Newberry). Plate in matrix. × ¾. E 1856, p. 102.



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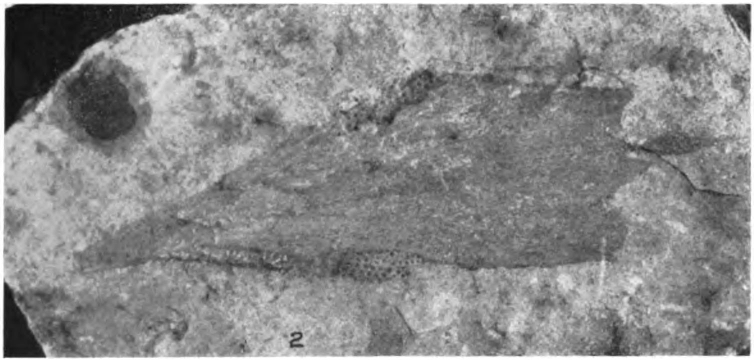

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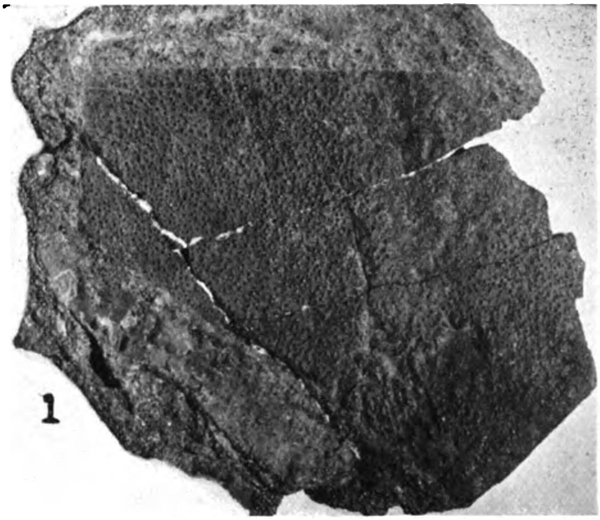
PLATE 30

Fig. 1. *Eczematolepis fragilis* (Newberry). Incomplete plate in matrix; outer face. It shows the ornamentation of fine tubercles. Natural size. E 2014, p. 102.

Fig. 2. *Acanthaspis* sp. Antero-ventrolateral, in matrix; inner, or visceral, face. Natural size. E 2024, p. 101.



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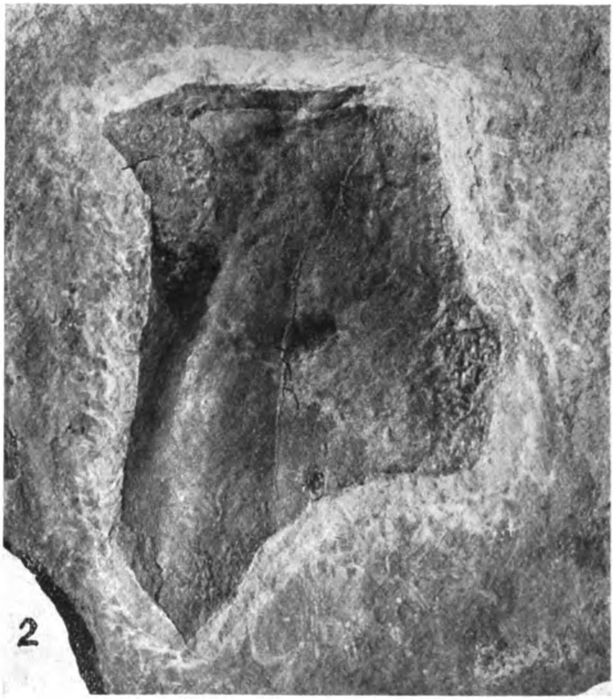

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PLATE 31

Holonema abbreviatum (Eastman).

Plate showing well the characteristic ornamentation; in matrix. Natural size. E 2025, p.102.

PLATE 32

Fig. 1. *Holonema rugosum* (Claypole). Cast of a complete plate. It shows tooth marks made by a Dinichthyid. Natural size. E 2513, p. 104.

Original in private collection of Mr. E. E. Teller, Buffalo, N. Y.

Fig. 2. *Phyllolepis elegans*, n. sp. Type. Plate in matrix Natural size. E. 2438, p. 21.

1

2

PLATE 33

Fig. 1. *Oëstophorus lilleyi* (Newberry). Fragmentary plate showing characteristic arrow-head-like ornamentation. × 2½. Conodont bed. E 2012, p. 105.

Fig. 2. *Holonema* sp. Cast of a fragmentary plate, remarkable for its thickness (over 1 cm.). Natural size. E 2512, p. 104.

Original in private collection of Mr. Edgar E. Teller, Buffalo, N. Y.

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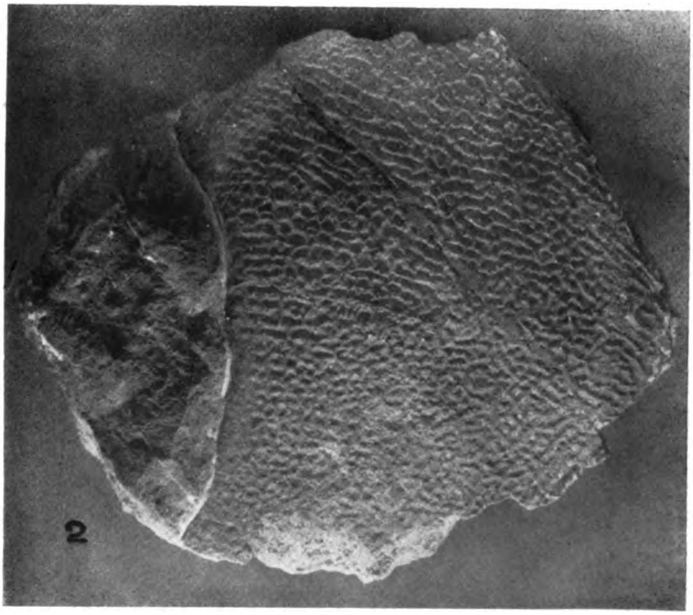

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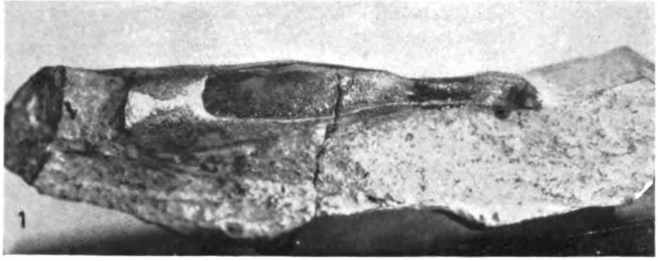
PLATE 34

Figs. 1, 3. *Ptyctodus calceolus* Newb. and Worthen. Right lower dental plate; natural size. 1, oral view, showing entire tritor; 3, inner view. E 1884, p. 108.

Fig. 2. Microsection of *Ptyctodus calceolus*, cut parallel to the side wall of the tritor.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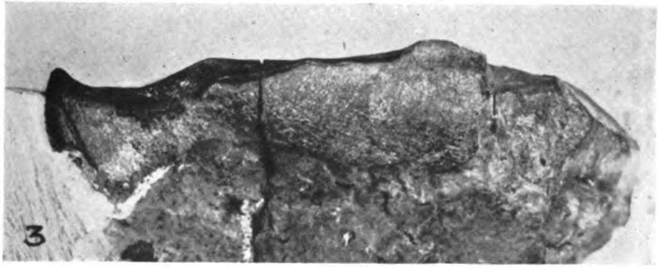
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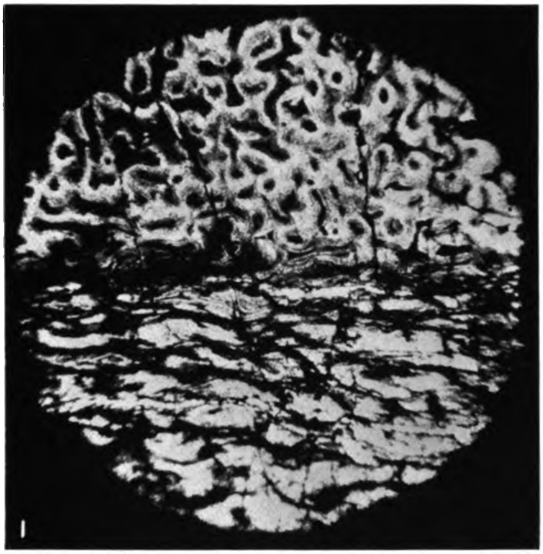
PLATE 35

Microsections of *Ptyctodus howlandi*, n. sp., p. 112.

Fig. 1. Section parallel to side wall of tritor.

Fig. 2. Portion of the same more highly magnified to show the radiating tubules.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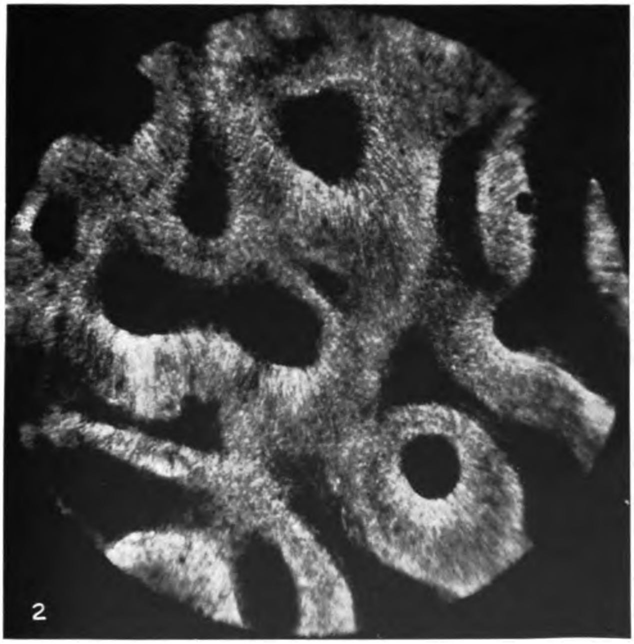
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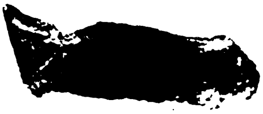
PLATE 36

All figures natural size

Figs. 1, 2, 10. *Ptyctodus calceolus* Newb. and Worthen.
1, 2, E 1913, p. 109.
10, E 2431, p. 109.
Figs. 3-9; 11, 12. *Ptyctodus compressus* Eastman.
3, E 1914, p. 110.
4, E 2410, p. 111.
5, E 1916, p. 110.
6, E 1917, p. 110.
7, E 2432, p. 115.
8, E 1914, p. 110.
9, E 1912, p. 110.
11, E 2433, p, 111.
12, E 1914, p. 110.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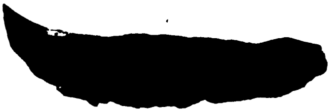
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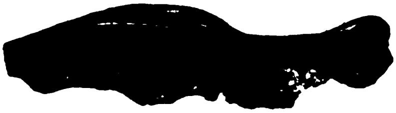
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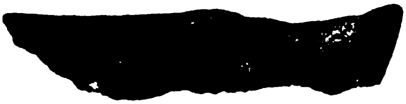
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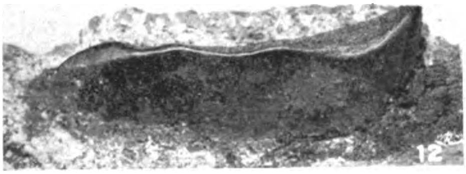
12


9

PLATE 37

All figures natural size

Figs. 1–8; 10–13. *Ptyctodus compressus* Eastman.

1, E 2406, p. 111.
2, E 1917, p. 110.
3, E 1914a, p. 110.
4, E 1914, p. 110.
5, E 1914a, p. 110.
6, E 1914, p. 110.

7, E 2433 (By inadvertence this is the same specimen as the one figured in Pl. 36, fig. 11.)

8, E 2432, p. 111.
10, E 2408, p. 111.
11, E 2404, p. 111.
12, E 1911, p. 110.
13, E 2408, p. 111.

Fig. 9, *Ptyctodus calceolus* Newb. and Worthen, E 1913, p. 109.


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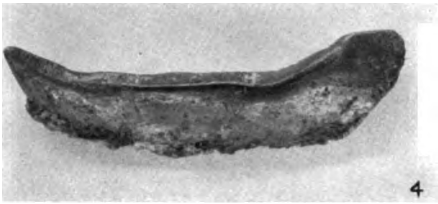
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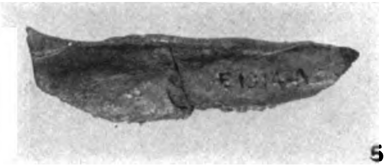
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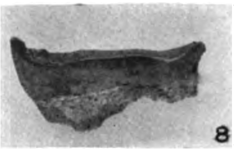
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PLATE 38

Ptyctodus howlandi, n. sp.

Figs. 1, 4, 5. Type. Left lower dental plate, × about ¾. E 1919, p. 112.
1, outer view; 4, inner view; 5, oral view (the anterior downward).

Fig. 2. Left lower dental plate, × ¾. E 2426, p. 115.

Fig. 3. Enlargement of surface view of tritoral area of type specimen.

Fig. 6. Right lower denta plate, natural size, showing tritoral area. E 2421, p. 115.

1

2

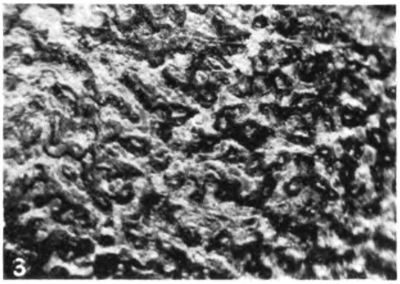

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PLATE 39

Rhynchodus ornatus, n. sp.

Figs. 1, 1a, 2. Cotypes. Two left lower dental plates, posteriorly incomplete, p. 117.

1, outer view, natural size. E 1950.

1a, the same enlarged about 1½ times, to show ornamentation of longitudinal lines.

2, outer view, natural size. E 1950 a. It shows the entire cutting margin, which is imperfect in Cotype 1. Note same style ornamentation as in Cotype 1, near lower margin.

Figs. 3, 3a. Anterior portion of a dental plate, ornamented on both outer and inner faces with a few pronounced, smooth tubercles. Natural size. E 1947 a, p. 118.

3, outer view. (The beak is toward the right.) Note 3 or 4 large, low tubercles.

3a, inner view. Note the beveled cutting margin, and 2 or 3 low, smooth tubercles.

Figs. 4, 4a. Dental plate, showing a few low, smooth protuberances or tubercles. Natural size. E 1947, p. 118.

4, outer view; 4a, inner. (The anterior cusp is not a beak; it has a specious appearance due to a part of the cutting margin being broken away.)

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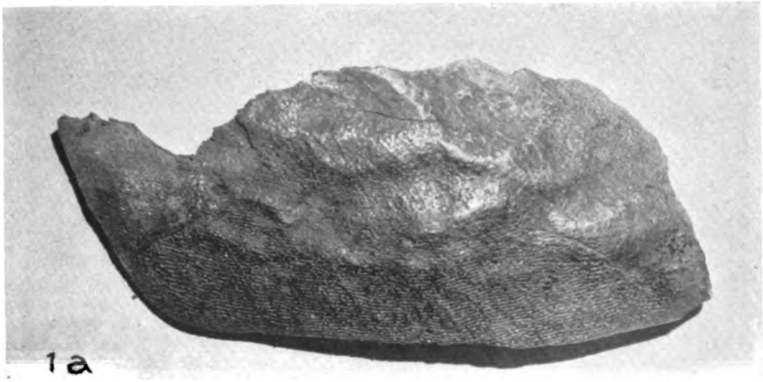
3a

4

4a



1a

PLATE 40

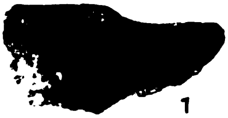
Figs. 1, 2, 3. *Ptyctodus* sp. Three tritors in profile view, to show progressive wearing down with use.

1, E 2407; natural size.
2, E 1926 (2); × ¾, p. 114.
3, E 1926; natural size, p. 114.

Fig. 4. *Palæomylus* sp. Small dental plate (juvenile?), in inner view; natural size. E 2448, p. 123.

Fig. 5. Anterior portion of dental plate, inner view; natural size. E 2449, p. 123.

Fig. 6. *Palæomylus lunaformis*, n. sp. Type. Dental plate, natural size. E 1928, p. 119.



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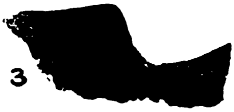

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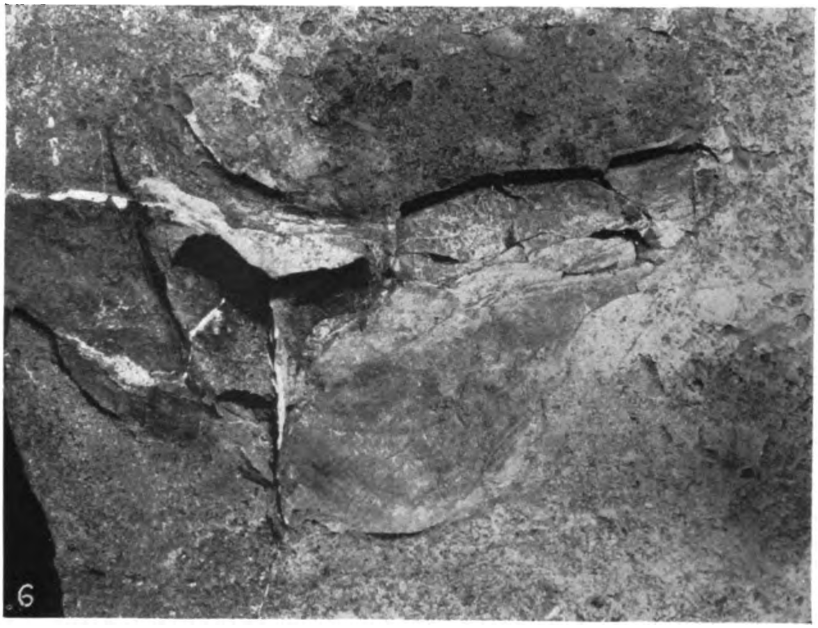

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PLATE 41

Figs. 1, 2. *Palæomylus* sp. A right lower dental plate (E 2446), and the beak of a left one (E 2453), p. 122.

1, profile view, × about $\frac{7}{8}$. 2, oral view, × $\frac{2}{3}$.

Figs. 3, 4, 5. *Palæomylus* sp. Three fragments of dental plates of same species as preceding, showing tritoral region. × $\frac{2}{3}$. E 1929 and E 1930, p. 122.

1

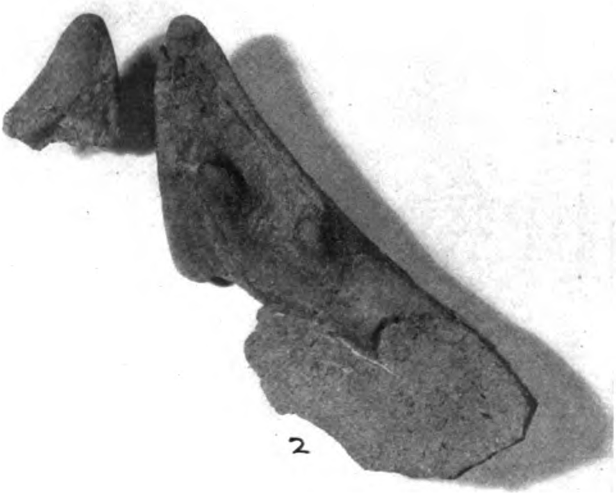

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PLATE 42

Deinodus bennetti, n. g., n. sp.

All figures natural size

Fig 1. An elongated, tapering plate, embedded with one face in matrix. Three sides are shown, the lateral ones ornamented with tubercles and the one between them smooth. The latter and one of the ornamented sides are shown in the figure. E 2451, p. 125.

Fig. 2. A plate resembling the preceding. The opposite side to the one shown in the figure is excavated with vascular surfaces as though for a pulp cavity. E 2461, p. 126.

Fig. 3. Type. Dental plate, slightly defective posteriorly, in outer view. It shows the beak, the bevelled functional margin, and the tubercles ornamenting the outer face. E 1856, and counterpart, E 2450, p. 123.


1


2


3

PLATE 43

Deinodus bennetti, n. g., n. sp.

All figures natural size

Fig. 1. Fragmentary plate, showing characteristic ornamentation. E 2460, p. 126.

Fig. 2. Plate, partly restored. E 2493, p. 126.

Fig. 3. An elongated, tapering element similar to the one in Plate 42, figure 1, showing near one end the tuberculated ornamentation. E 2468, p. 126.

1

2

3

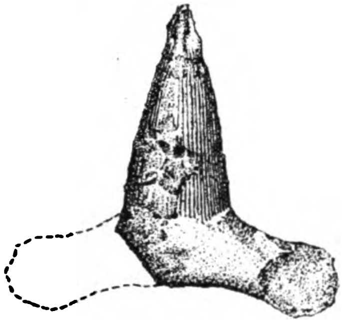
PLATE 44

Figs. 1, 1a. *Cladodus urbs-ludovici* Eastman. Tooth in front (1), and lateral (1a), views. × 3. E 1900., p. 139.

Fig. 2. *Anodontacanthus pusillus*, n. sp. Type. Small spine, incomplete at both extremities. × 3. E 1915, p. 156.

Figs 3, 3a, 3b. *Dittodus priscus* (Eastman). 4. E 1901, p. 144.
3. Tooth in front view, showing ornamentation.
3a. Outline of side view of another tooth, to show antero-posterior width of root and position of the "button."
3b. Tooth from above, to show entire root and the "button."

Fig. 4. *Orodus devonicus*, n. sp. Type. Tooth, × 3. E 1903, p. 153.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1a


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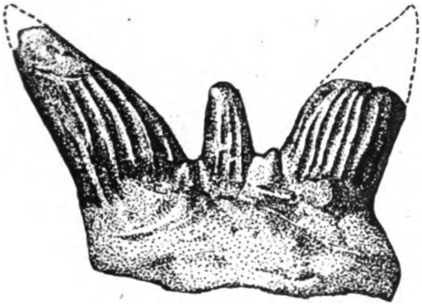
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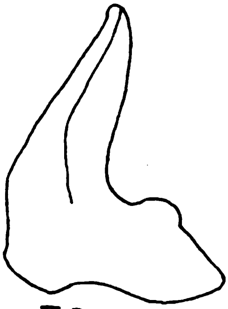
3a


3b


4

PLATE 45

Cladoselache acanthopterygius Dean. Shark, lacking head, but displaying pectoral fins and entire length of body to caudal. × ⅓. E 2474, p. 128.

PLATE 46

Cladoselache brachypterygius Dean. Shark lacking caudal extremity. The pectorals are well shown. × ¼. E 2475, p. 130.

PLATE 47

Cladoselache desmopterygius Dean. Front half of a shark, showing well the head and one pectoral fin. × ⅓. E 2476, p. 130.

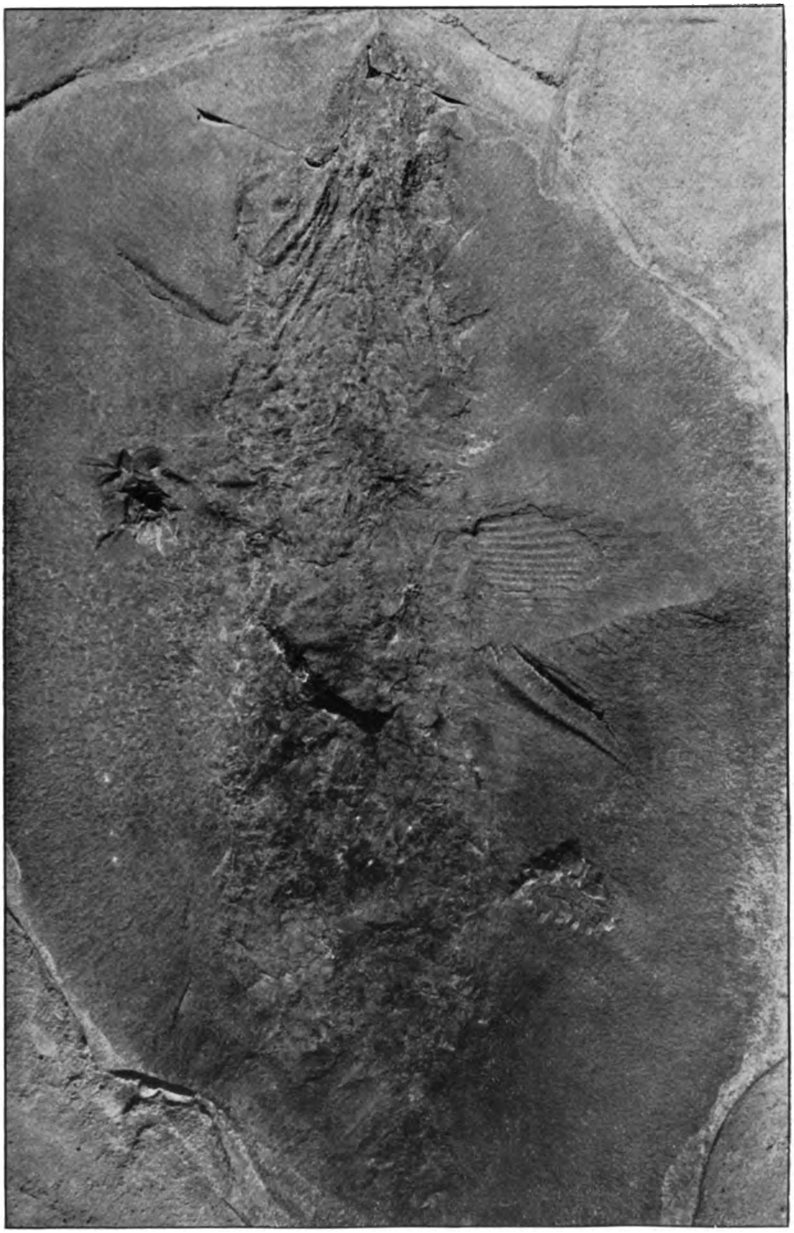

PLATE 48

Cladoselache fyleri (Newberry). Complete shark, 39 cm. in length, in ventra. view. It shows well the pectorals and the lateral caudal keels. × ⅓. E 2480, p. 134.

The black streaks extending from the head diagonally toward the upper corners of the figure, and also three lesser ones in the lower half of the fish, are formations in the matrix and not part of the shark.

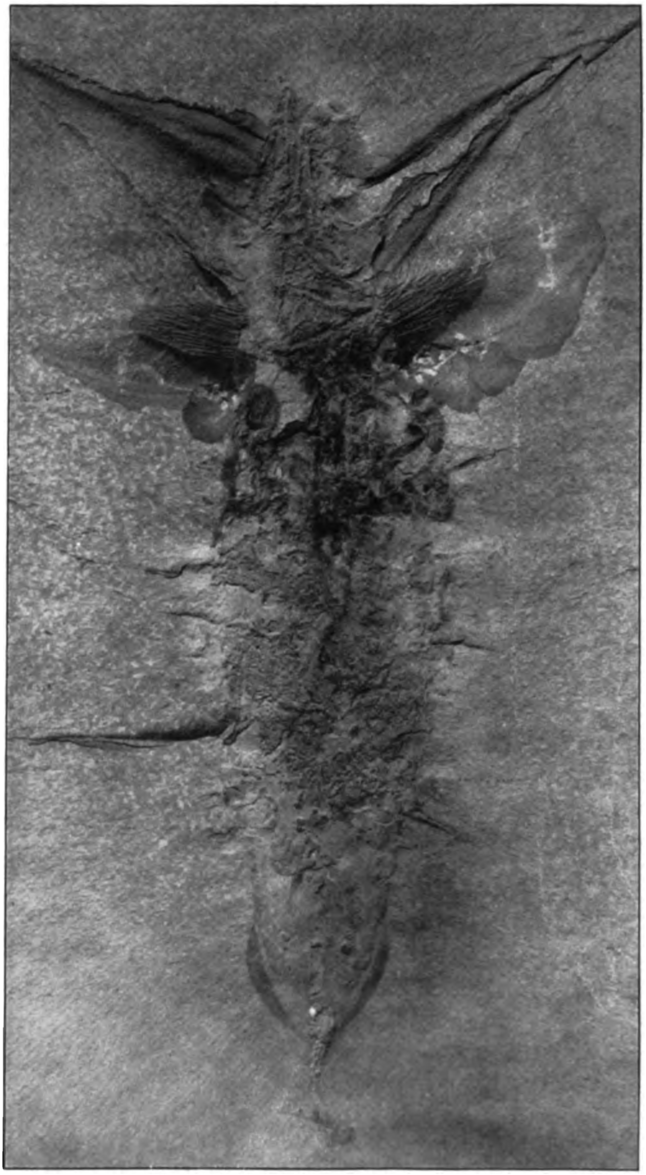

PLATE 49

Cladoselache kepleri (Newberry). Complete shark, 160 cm. in length, as far as preserved; in ventral view. × $\frac{1}{10}$. It shows well the blunt head, the pectorals, one ventral, and one lobe of the caudal fin. E 2481, p. 135.

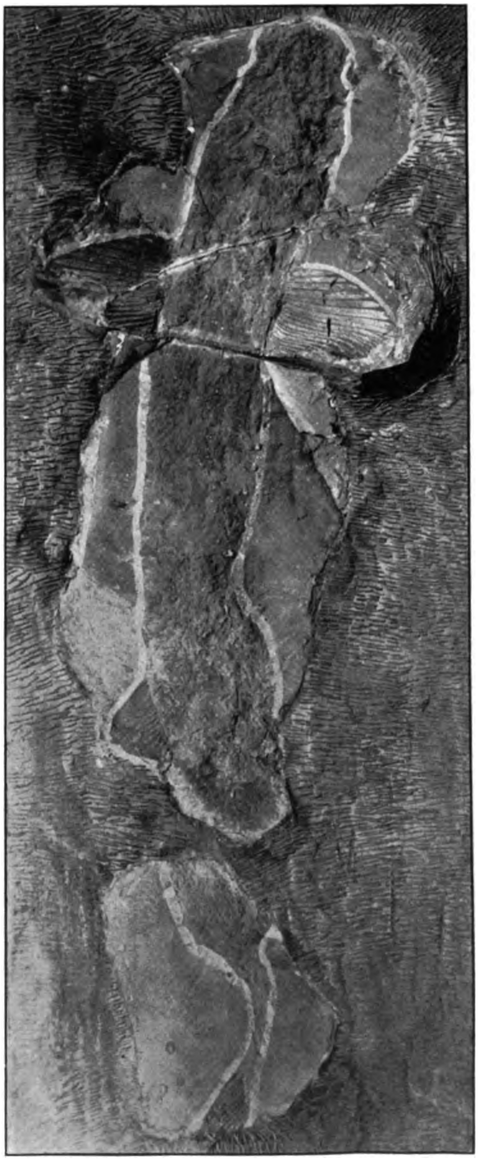

PLATE 50

Cladoselache kepleri (Newberry). Part of a large shark showing the ventral fins. × ½. E 2482, p. 137.

PLATE 50

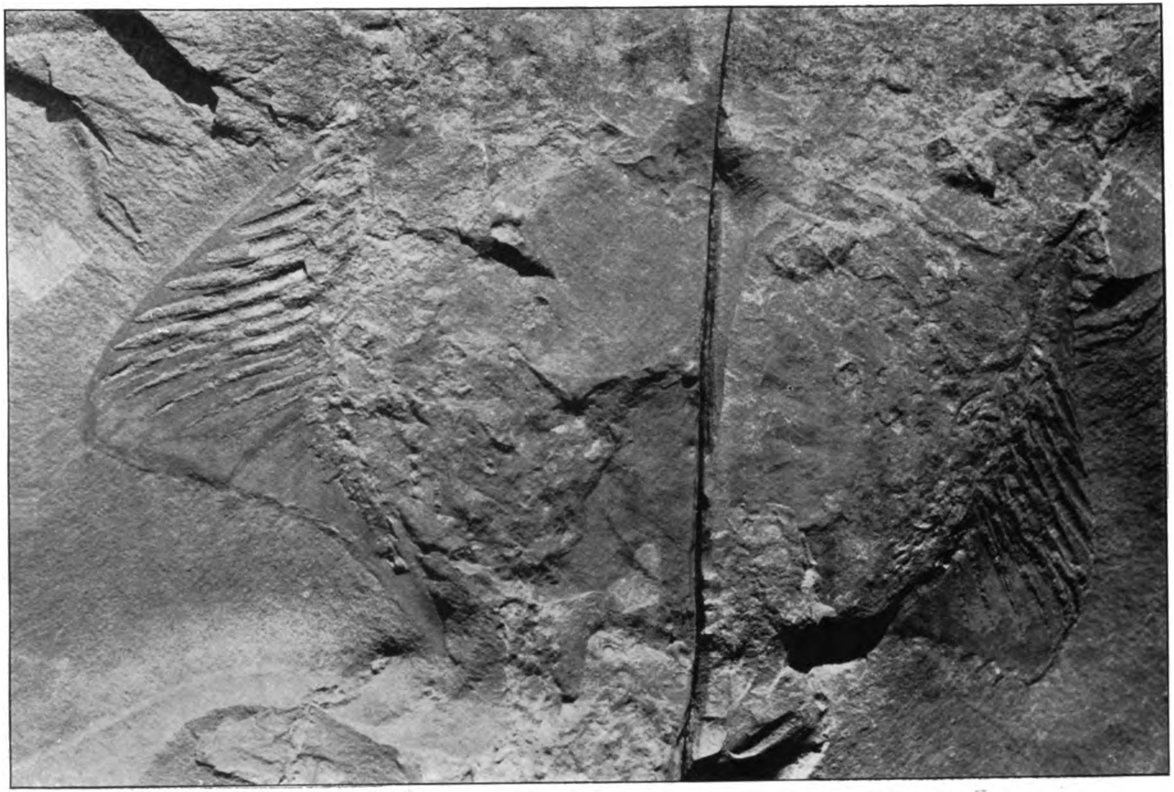

PLATE 51

Fig. 1. *Ctenacanthus nodocostatus*, n. sp. Type. Complete spine. Original is an impression in sandstone, and the figure is from a wax squeeze of it. Natural size. E 2083, p. 159.

Fig. 2. *Acanthodes concinnus* Whiteaves. Enlargement of shagreen, × about 15. Taken from specimen E 2485 (see text-fig. 50), p. 141.

Fig. 3. Acanthodin spine, in matrix. × 6. E 2486, p. 142.

Fig. 4. *Acanthodes concinnus* Whiteaves. Pectoral fin-spine of specimen of which shagreen is figured (this plate, fig. 2). E 2485. × 3½, p. 141.

PLATE 51

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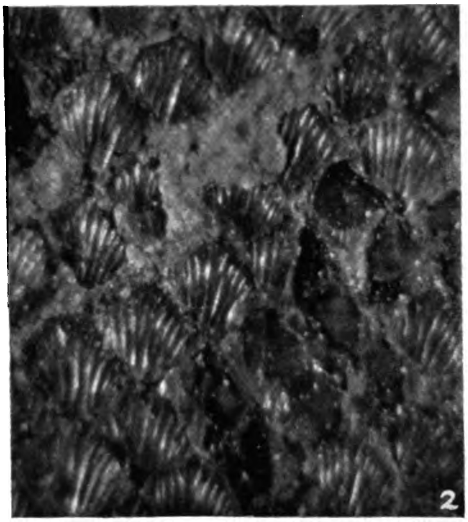

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PLATE 52

Fig. 1. *Gamphacanthus uddeni* (Lindahl). Spine in matrix; natural size. E 1875, p. 164.

Fig. 2. *Ctenacanthus wrighti* Newberry. Fragment of a spine showing characteristic ornamentation. × 1⅓. E 1904, p. 161.

Figs 3, 5. *Gyracanthus sarlei*, n. sp. Type, E 2487, p. 142.
3. Proximal half of spine, in matrix; ⅚ size.
5. Cross-section, × 5.

Fig. 4. *Gyracanthus* sp. Spine, × 1½. E 2489, p. 144.

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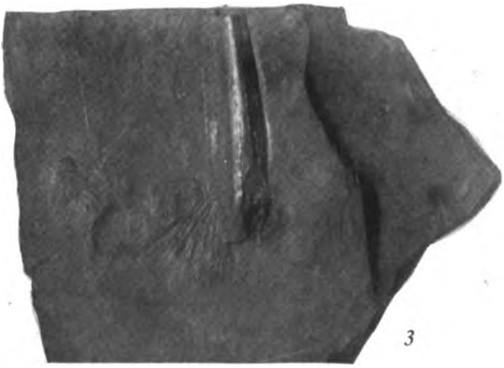

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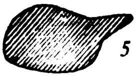

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PLATE 53

Fig. 1. *Machærancanthus major* Newberry. Distal half of spine, in matrix ×⅘. E 1849, p. 166.

Fig. 2. *Machæracanthus major* Newberry. Distal half of spine, in matrix. ×⅘. E 1848, p. 166.

Fig. 3. *Machæracanthus peracutus* Newberry. Distal half of spine, in matrix. × ⅘. E 1850, p. 167.

Fig 4. *Machæracanthus* sp. Distal extremity of spine, in matrix. × ⅘. E 2514, p. 168.


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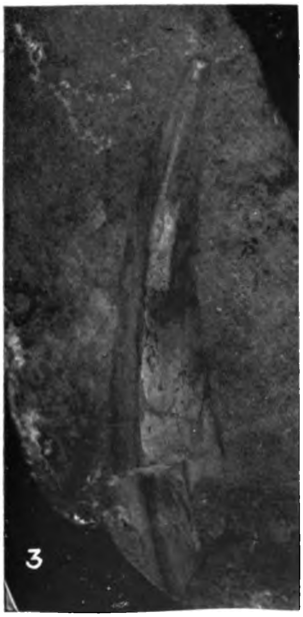
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PLATE 54

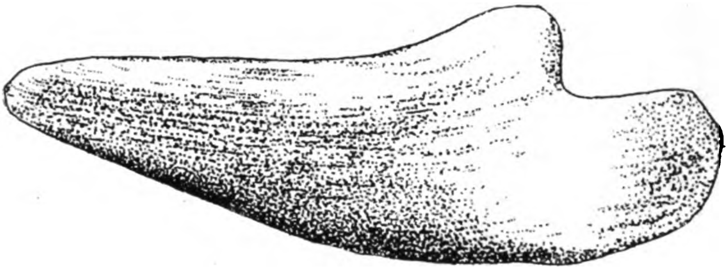
Figs. 1, 1a, 2. *Stethacanthus præcursor*, n. sp., p. 169.

1. Lateral view of spine, based on the two cotypes; natural size.

1a. Cross-section at about one-third from apex; natural size.

2. A nearly complete spine—the more perfect of the two cotypes; natural size. E 1908.

Fig. 3. *Stethacanthus depressus* (St. John and Worthen). Small spine, × 2. E 2516, p. 170. (Original is an impression in sandstone, and the figure is from a wax squeeze of it.)



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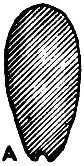


1A

2

3

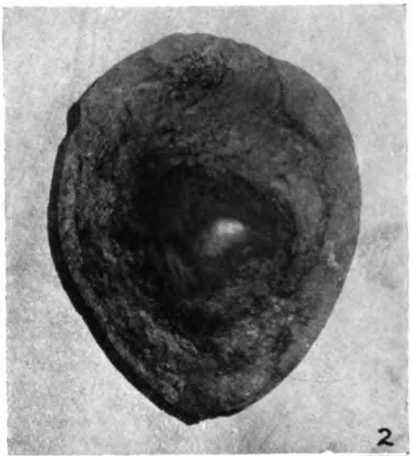
PLATE 55

(All figures natural size)

Figs. 1, 2. *Synthetodus calvini* Eastman. Dental plate. E 2017, p. 150.
1, inserted face; 2, oral face, showing a large worn boss.

Fig. 3. *Acmoniodus clarkei*, n. g., n. sp. Type. Large dental plate, in oral view; nat. size. It shows an elliptical anterior tritor, and a larger, subtriangular, posterior tritor. (Cf. text-fig. 53.) E 2575, p. 152.

1



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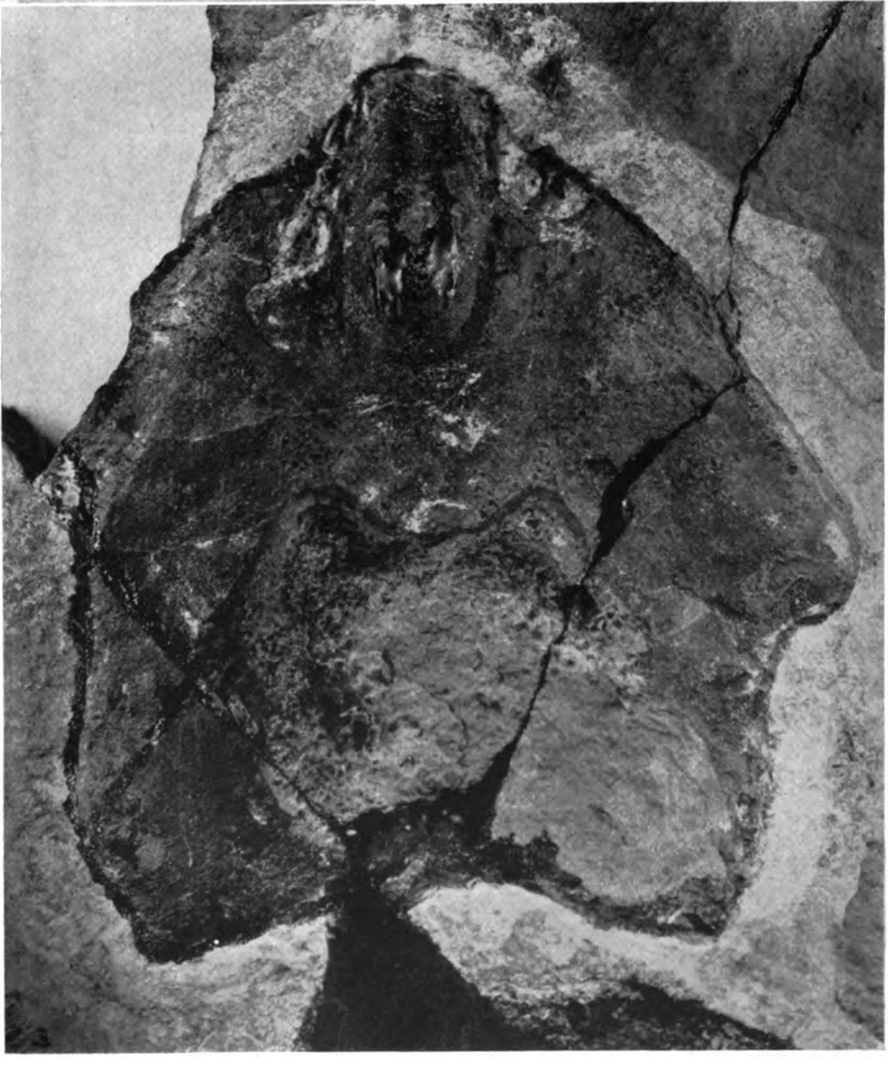

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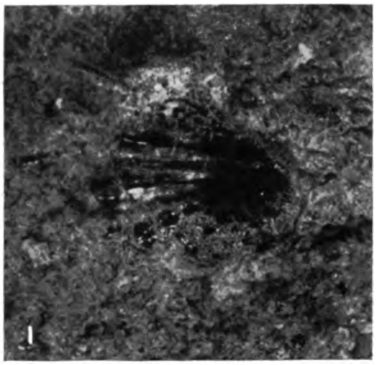
PLATE 56

Fig. 1. *Dipterus* sp. A small dental plate, in matrix. × 2. E 2015, p. 171.

Figs. 2, 2a. *Dipterus gemmatus*, n. sp. Type. Dental plate, in matrix, E 2517, p. 170. Fig. 2 is × 3; 2a is × 5, to bring out the surface punctæ.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2


2a

PLATE 57

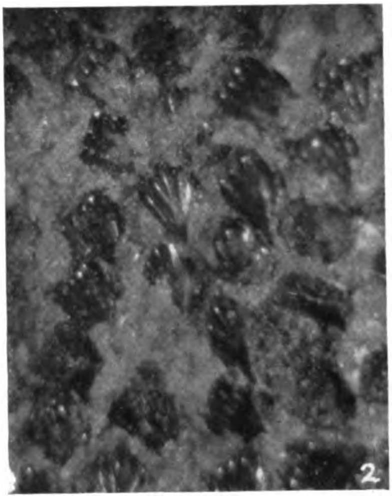
Figs. 1, 2. *Cheirolepis canadensis* Whiteaves. Enlargement of scales, × about 25.
Both figures from E 2558, p. 181.

Fig. 3. *Scaumenacia curta* (Whiteaves). Impression of posterior portion of upper surface of head, showing sutures and sensory canals. Near the head is seen the dentition. E 2521, p. 172.

Fig. 4. *Scaumenacia curta* (Whiteaves). Dentition shown in preceding figure, ×3.

Figs. 5, 6, 7. Enlargement of shagreen scales found isolated in the Conodont bed. Fig. 6 is the under side of a scale like that in Fig. 5, and shows a flange for overlap.


1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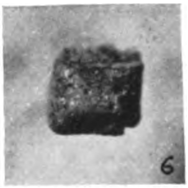
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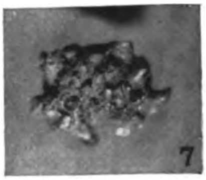
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PLATE 58

Onychodus sigmoides Newberry

Fig. 1. Laniary tooth from mandible, × ⅚. E 1873, p. 180.

Fig. 2. Series of 6 premandibular teeth, with their supporting symphyseal bone; natural size. E 1871, p. 180.

Fig. 3. Left mandible, lacking anterior extremity; outer view. × ⅙. E 2556. (Cf. text-fig. 59.) p. 179. *ang*, angular; *art*, articular; *den*, dentary.

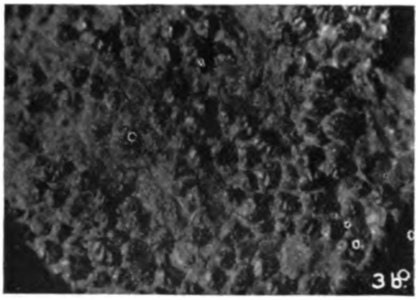
3a. Tooth of preceding enlarged 3 times.

3b. Enlargement of surface ornamentation of mandible shown in Figure 3.


1.


2.


3a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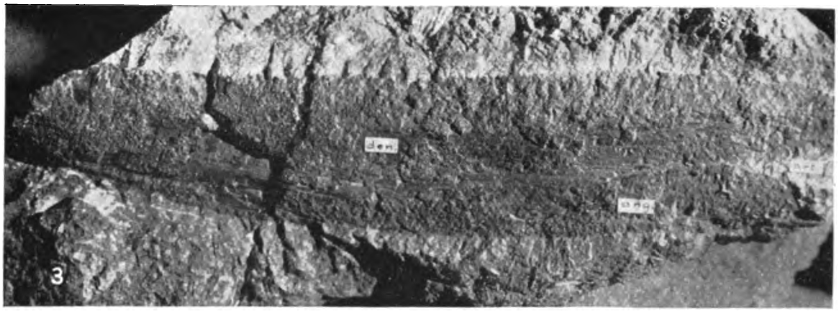
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PLATE 59

Rhadinichthys devonicus (Clarke)

Imperfect fish on shale, showing outline of body and the caudal fin. Natural size. E 2044, p. 184.

PLATE 69

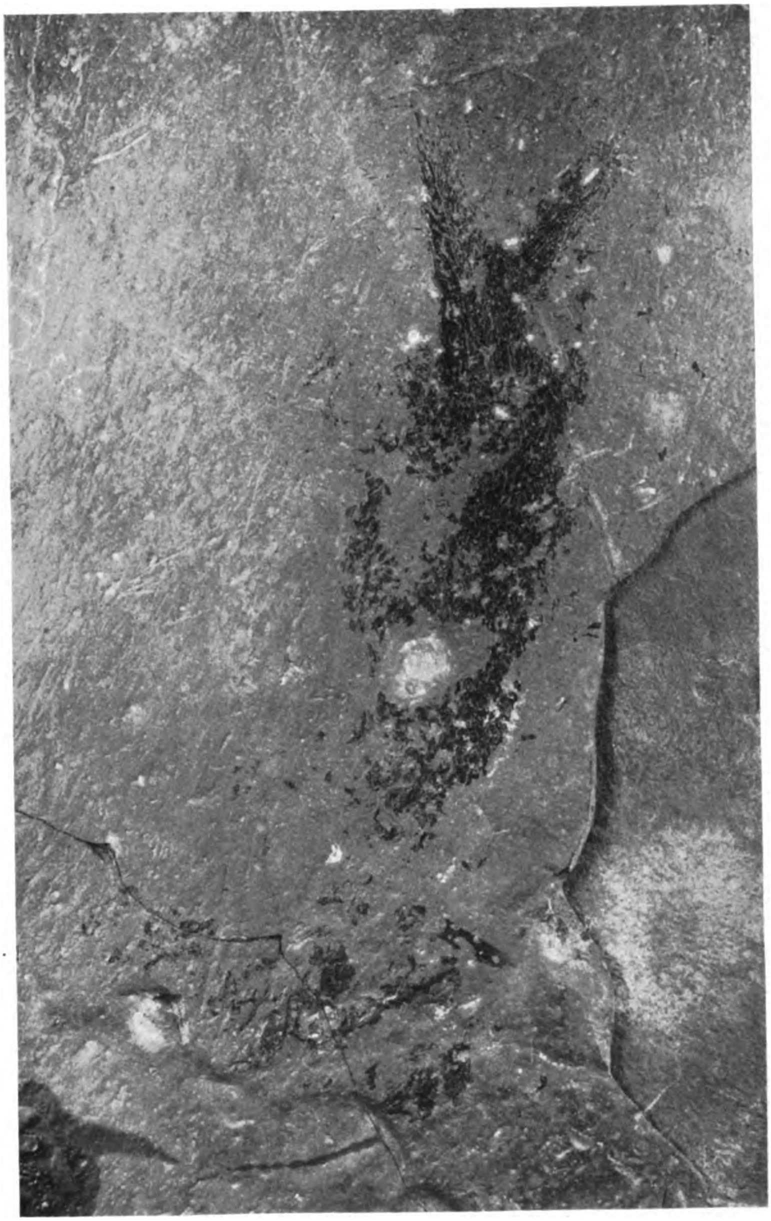

PLATE 60

Rhadinichthys devonicus (Clarke)

Fig. 1. Cleithrum, × 3½. E 2048. (Cf. text-fig. 61 *A*.) h. 184.

Fig. 2. Operculum, × 3. E 2047. (Cf. text-fig. 61 *B*.) p. 184

Fig. 3. Cranial plates, × 5. E 2045, p. 184.


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2


3

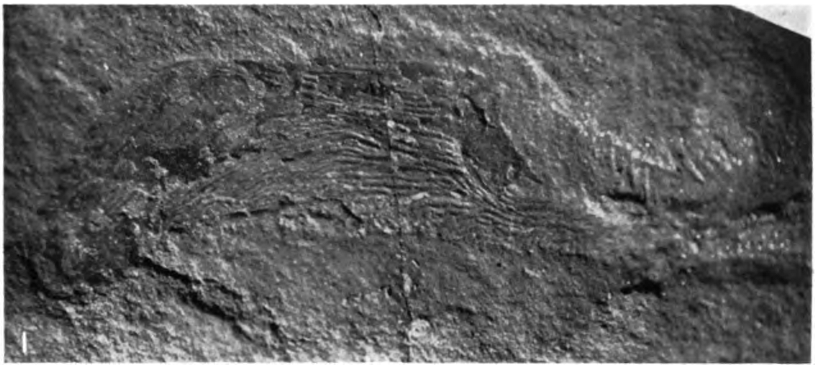
PLATE 61

Rhadinichthys devonicus (Clarke). × 4

Fig. 1. Right maxilla; outer view. It shows well the surface ornamentation. E 2051, p. 184.

Fig. 2. Right maxilla; outer view. The surface ornamentation is denuded, but the teeth are well shown. (Cf. text-fig. 61 *C*.) E 2067, p. 185.

Fig. 3. Right maxilla, defective posteriorly; outer view. E 2050, p. 185.



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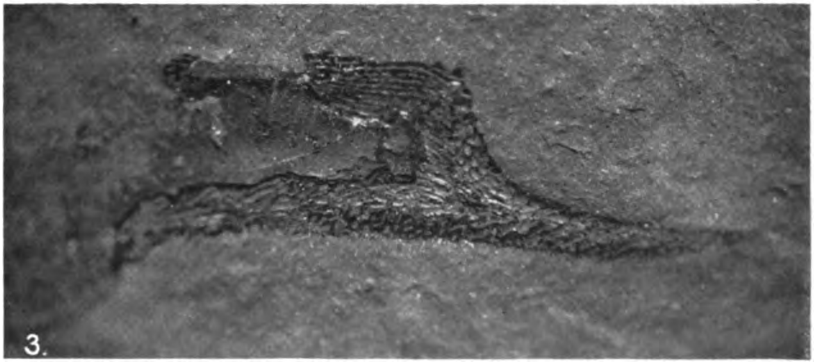

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PLATE 62

Rhadinichthys devonicus (Clarke)

Fig. 1. Left mandible, denuded of surface ornamentation. × 4. E 2055, p. 184.

Figs. 2, 3. Detached scales, magnified, to show surface ornamentation. E 2061, p. 184.

Fig. 4. Cranial plates and scales, showing characteristic ornamentation of his species. × 5. E 2049, p. 184.

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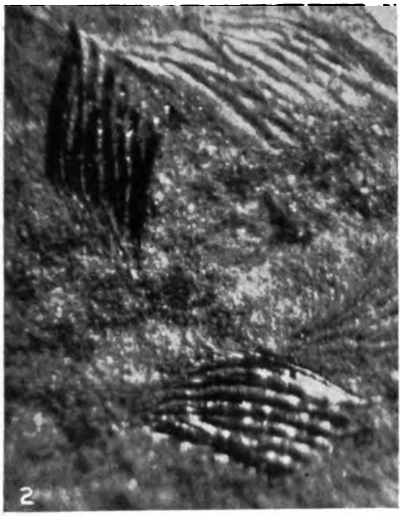

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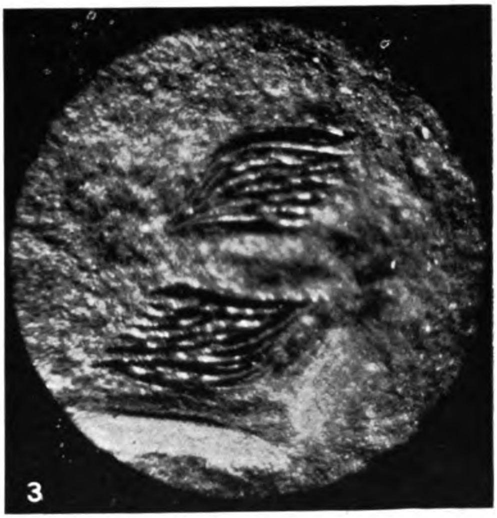

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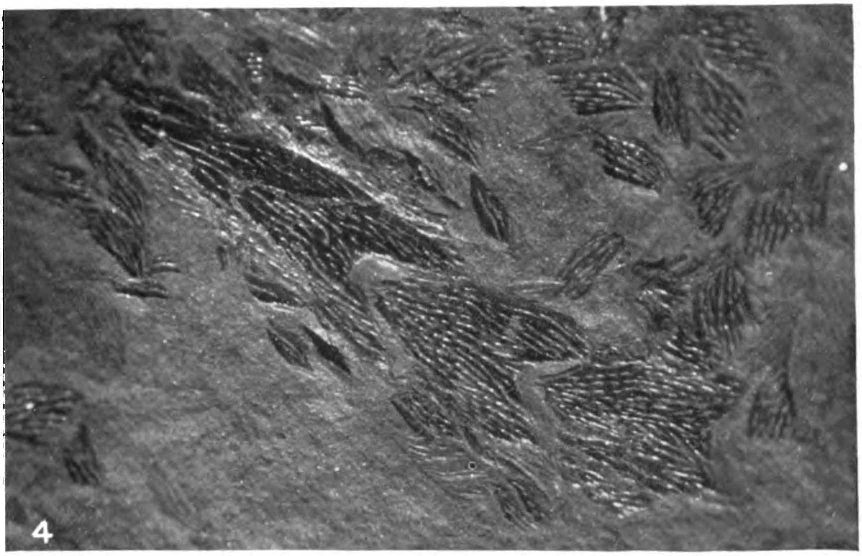

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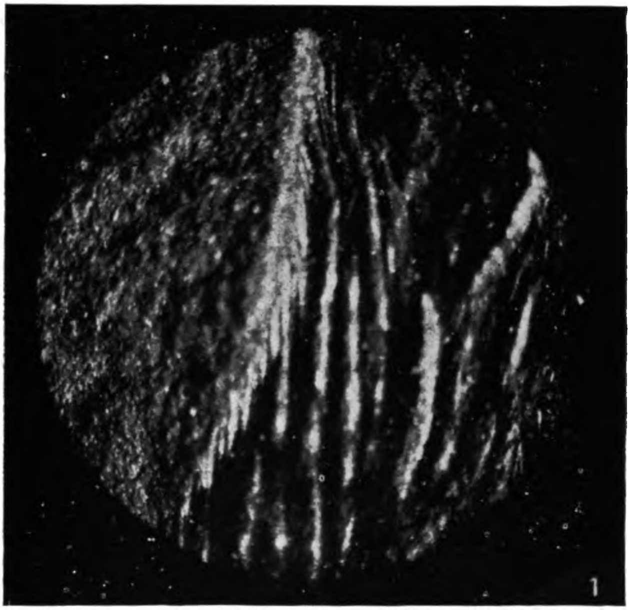
PLATE 63

Figs. 1, 2. *Rhadinichthys devonicus* (Clarke). Fin-rays, highly **magnified.** Part of same specimen as cranial plates shown in Plate 62, figure 4. E 2049, p. 184.

Fig. 3. *Rhadinichthys antiquus* (Williams). Caudal extremity of fish, showing scales and the fulcra of lower lobe. × 5. E 2065, p. 186.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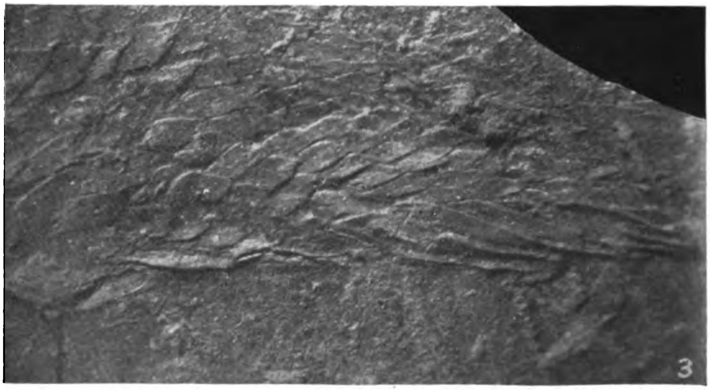
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PLATE 64

Rhadinichthys antiquus (Williams)

Fig. 1. Left cleithrum. × 2½. E 2068, p. 186.
Fig. 2. Ridge scale, outer view. × 9. E 2074, p. 187.
Fig. 3. Ridge scale, inner view. × 8.
Fig. 4. Ridge scales, inner view. × 8. E 2074, p. 187.
Figs. 5, 6. Detached scales. × 9. E 2074, p. 187.


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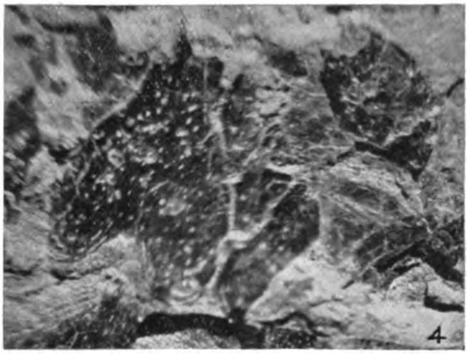
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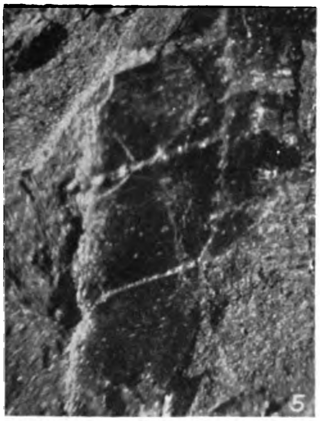
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PLATE 65

Fig. 1. *Rhadinichthys devonicus?* (Clarke). Right maxilla, outer view, showing nearly entire outline and the surface ornamentation. × 4. E 2565, p. 185. Cleveland shale; Ohio.

Fig. 2. *Rhadinic thys devonicus* (Clarke). Right maxilla, in outer view; from the Portage shale, near Buffalo, N. Y., for comparison with the preceding from the Cleveland shale. × 4. E 2c66, p. 185.

Fig. 3. *Rhadinichthys devonicus?* (Clarke). Mandibles, separated from each other and both displaying the outer, ornamented surface. × 4. E 2566, p. 185. Cleveland shale; Ohio.

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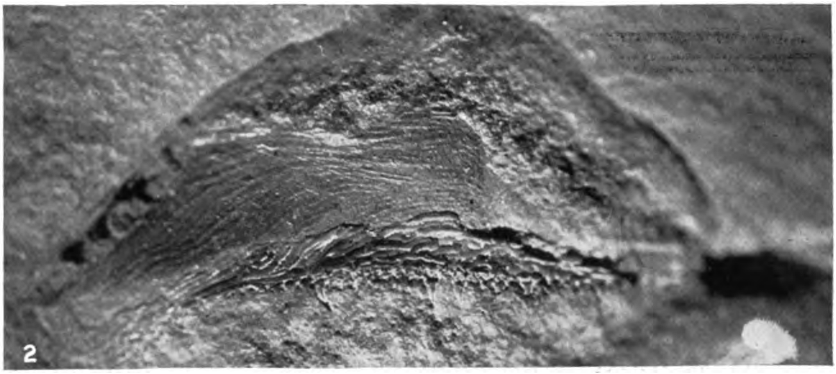

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PLATE 66

Rhadinichthys elegantulus (Eastman)

Figs. 1, 2. Two enlargements of the same fish. 1, is × 3; 2, is × 2½. E 2092, p. 190.

Fig. 3. Caudal extremity of an imperfect fish. The figure shows well the dorsal and anal fins. × 4. E 2093, p. 100.


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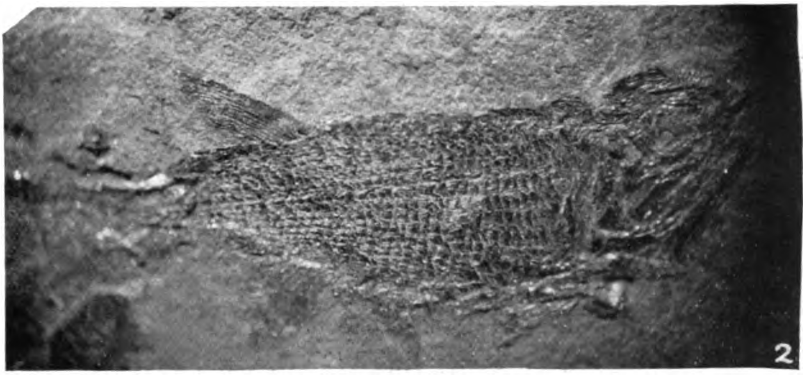
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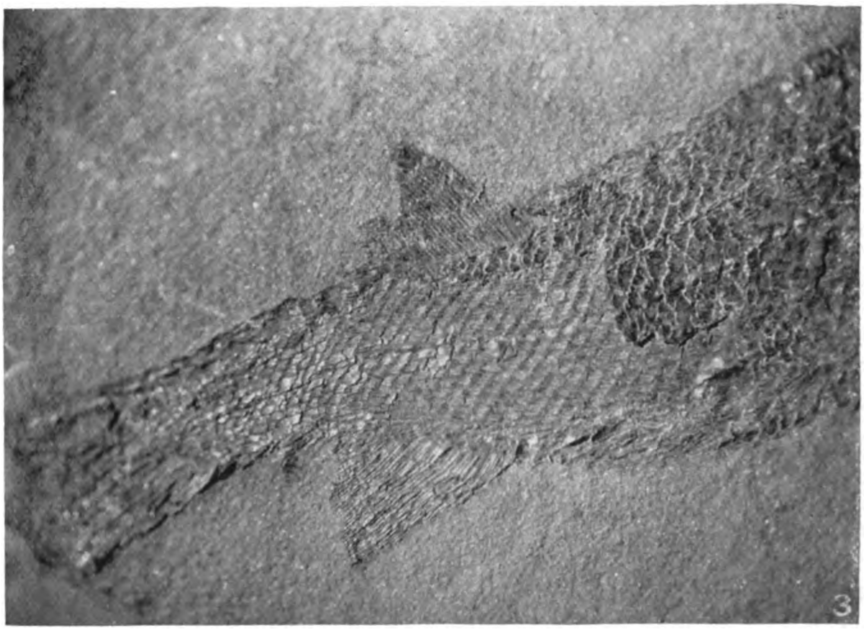
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PLATE 67

Dictyopyge macrura (W. C. Redfield)

A slab of shale containing remains of 10 fishes, one of them (the bottom one in the figure), almost complete. × ⅜. E 2126. p. 193. Triassic; Richmond, Va.

PLATE 68

Lepisosteus simplex Leidy. × about ⅕. E 2150, p. 196. Green River shales: Wyoming.

PLATE 69

Fig. 1. *Stenognathus ringuebergi* (Newberry). Slab of shale, 65 by 37 cm., showing the dorsomedian (*DM*), a postero-ventrolateral plate (*V*), and portion of the notochord (*N*) with neural (*n. a.*) and haemal (*h. a.*) arches. × $\frac{1}{5}$. E 2595, p. 69.

Fig. 2. *Dinichthys tenuidens*, n. sp. Type. Left mandible, in outer view. ×$\frac{2}{5}$. E 2596, p. 55.

1

PLATE 70

Fig. 1. *Coccosteus parvulus*, n. sp. Cranial shield, represented chiefly by the impression; the bone is shown only in regions of left orbit, left marginal, and the median occipital. On the left marginal the lateral canal is to be seen. × 1. E 2597, p. 30.

Fig. 2. *Eusthenopteron foordi* Whiteaves. Pectoral fin, × 1. Belongs to specimen, E. 2594, p. 178.

Fig. 3 *Dinichthys* sp. Left mandible, in inner view, × ⅓. Collected and presented by Mr. E. J. Armstrong, Erie, Pa. E 2598, p. 54.


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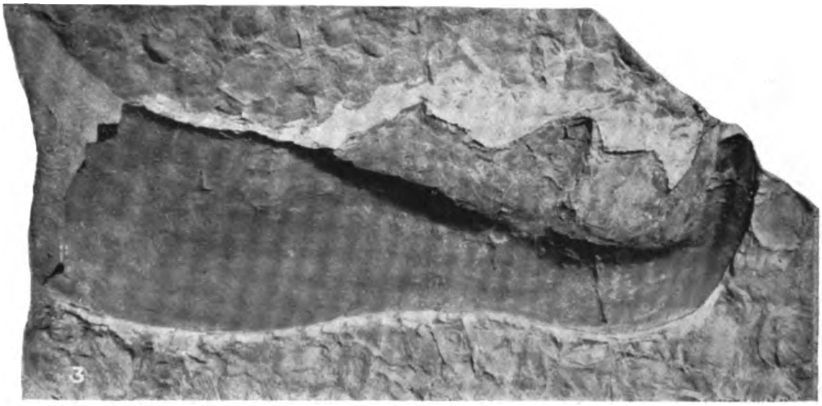
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INDEX

Detailed descriptions of species are referred to by **black face** numbers. Illustrations are indicated by an *. Mere incidental references to species are as a rule omitted.